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Rainbow Trout Production and Water Quality in Eastern South Dakota Dugouts

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RAINBOW TROUT PRODUCTION AND WATER QUALITY
IN EASTERN SOUTH DAKOTA DUGOUTS

BY

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IN EASTERN SOUTH DAKOTA DUGOUTS

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science, and is acceptable for meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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RAINBOW TROUT PRODUCTION AND WATER QUALITY

IN EASTERN SOUTH DAKOTA DUGOUTS

Abstract

William Lee Vodehnal

Nine-hundred-fifty-four rainbow trout (Salmo gairdneri) were stocked into 18 eastern South Dakota dugouts in April 1980 to determine the feasibility of dugouts for raising annual fish crops. Trout growth was compared between dugouts by stocking rate (1977/ha, 1483/ha, 988/ha, and 494/ha) and feeding combination [fathead minnows (Pimephales promelas) and supplemental feed, supplemental feed, and trout alone]. Chemical-physical properties were also monitored in an old and new unstocked dugouts from July 1980 to July 1981.

Growth was greater for 988/ha rainbow trout than the other stocking densities during the April 1980 to July 1980 sampling period. Mean total length increased from 139.7 to 230.3 mm and mean weight increased from 27.8 to 158.5 g. Due to high mortality (97.4%), it is believed that the optimal stocking density or production of trout was not totally determined. There was insufficient evidence to state that fathead minnows and supplemental feeding enhanced growth of trout.

The old and new dugouts were comparable in chemical-physical properties by increasing from a summer minimum to winter maximum. Differences were detected in dissolved oxygen, hardness, and sulfate concentrations.

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INTRODUCTION

Since the mid 1930's, approximately 100,000 private dugout ponds have been excavated in South Dakota utilizing technical services provided by the Soil Conservation Service (John Farley, Soil Conservation Service, Huron, South Dakota, personal communication). These ponds provide for livestock watering, wildlife habitat, recreation, fire control, and other uses. Because of the shallowness and therefore potential of winter-kill, their suitability for maintaining sustained fish populations is minimal. Fish production on an annual basis however may be possible.

The purposes of this study were; (1) to evaluate the potential of dugout ponds in eastern South Dakota for raising annual crops of rainbow trout (*Salmo gairdneri*), and (2) to determine a one year cycle of chemical-physical properties in two unstocked dugout ponds, one old and one new.

Dugout ponds, producing annual crops of trout, could provide an income source to landowners. Rainbow trout 127-152 mm in total length can be purchased for 23¢-40¢ per fish with reimbursement values for 229-279 mm fish of $1.50-$2.10 per fish (American Fisheries Society 1978). The advantages of marketability, adaptability, and rapid growth of rainbow trout (Helfrich et al. 1979) indicate qualities desirable for raising an annual fish crop in typical winterkill environments. The trout could also be used by the landowners as a source of family food or as a recreational fishery.

Rainbow trout have been cultured with variable success in lakes and ponds in the northern United States and Canada by stocking fingerlings in the spring and harvesting them in the fall (Johnson et al. 1970; Sunde et al. 1970; Myers 1973; Hahn 1974; Lawler et al. 1974; Olson and Hedner 1980) and in the southern states by stocking in the fall and harvesting in the spring (Collins 1972; Hill et al. 1972; Reagan and Robinette 1975; Tatum 1976; Newton et al. 1977; Jensen 1979; Halverson et al. 1980). Initial fish size and stocking density are important to maximum seasonal fish production of marketable value. Lawler et al. (1974) found that a 50-80 mm fish could be of usable size (200 g) in one growing season without supplemental feeding when stocked at under 2500 fish/ha. Higher fish stocking densities could be used if supplemental feed was provided.

Whether the intention is to maximize growth or to produce fish of minimum usable size in the shortest time, water quality monitoring is important (Bennett 1970; Weatherley 1976; Boyd 1979). The eutrophic conditions in eastern South Dakota lakes and ponds threaten fish survival and growth because of fluctuations in dissolved oxygen and temperature. Summer mortality of rainbow trout prevailed in Canada when dissolved oxygen fell below 6 mg/l (Barica 1975; Ayles et al. 1976). Mortality was attributed to either algal bloom collapses or temperature increases which reduced the solubility of oxygen in water. The upper lethal water temperature for rainbow trout is approximately 27 C (Cherry et al. 1977; Lee and Rinne 1980); the optimal temperature is 13 C (Garside and Tait 1958). In addition, many other chemical-physical properties interact to affect optimal growth and survival rates.

STUDY AREA

Eighteen dugout ponds located in Brookings, Kingsbury, and Moody counties of eastern South Dakota were used during the fish production portion of the study (Fig. 1). Two additional dugout ponds located in Brookings County were used during the chemical-physical properties portion of the study. Landowner names and pond locations are presented in Appendices 1 and 2. Pond selection was based on criteria described by Johnson and Hasler (1954), Johnson et al. (1970), and Barica (1975) as suitable for trout growth and survival. Ponds were considered acceptable if: (1) no prior fish stockings had been made, (2) the minimum depth was at least 2 m, and (3) the risk of drainage out of the watershed was minimal. Selection was made following field observations in winter, 1980.

The study area is part of the Big Sioux River drainage and is located in the Coteau des Prairies, a highland region of glacial origin between the Minnesota-Red River lowland and the James River lowland (Westin et al. 1967). Chernozem soils predominate and the region is classified as a cool-moist climate. The average temperature for the region is 6.5 C with extremes of -40.5 to 42.7 C (Spuhler et al. 1971). Average annual precipitation is between 50.8 and 55.9 cm (Westin et al. 1967).

Dugouts are rectangular ponds which generally depend on surface runoff and groundwater seepage for their water supply (Fig. 2). Design criteria (Soil Conservation Service 1978) specify that bottom widths and lengths be at least 3.0 m and 12.2 m, respectively, but the minimum bottom area be 46.5 m^2 or more at the design depth. The minimum water

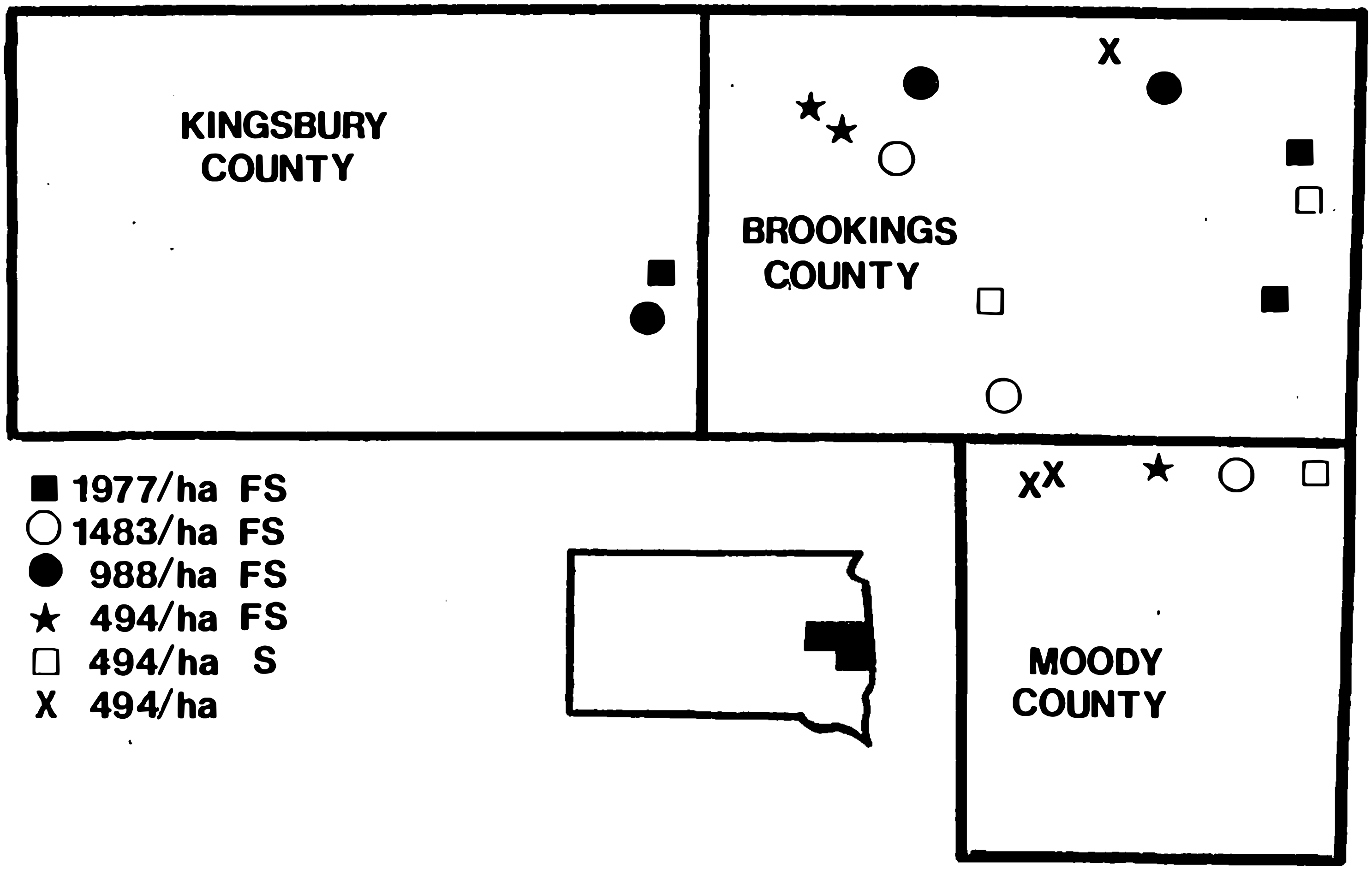

Figure 1. Distribution of dugouts stocked with rainbow trout (*Salmo gairdneri*), according to density stocked and feeding combination, South Dakota, 1980. (F = fathead minnows (*Pimephales promelas*), S = supplemental feed)

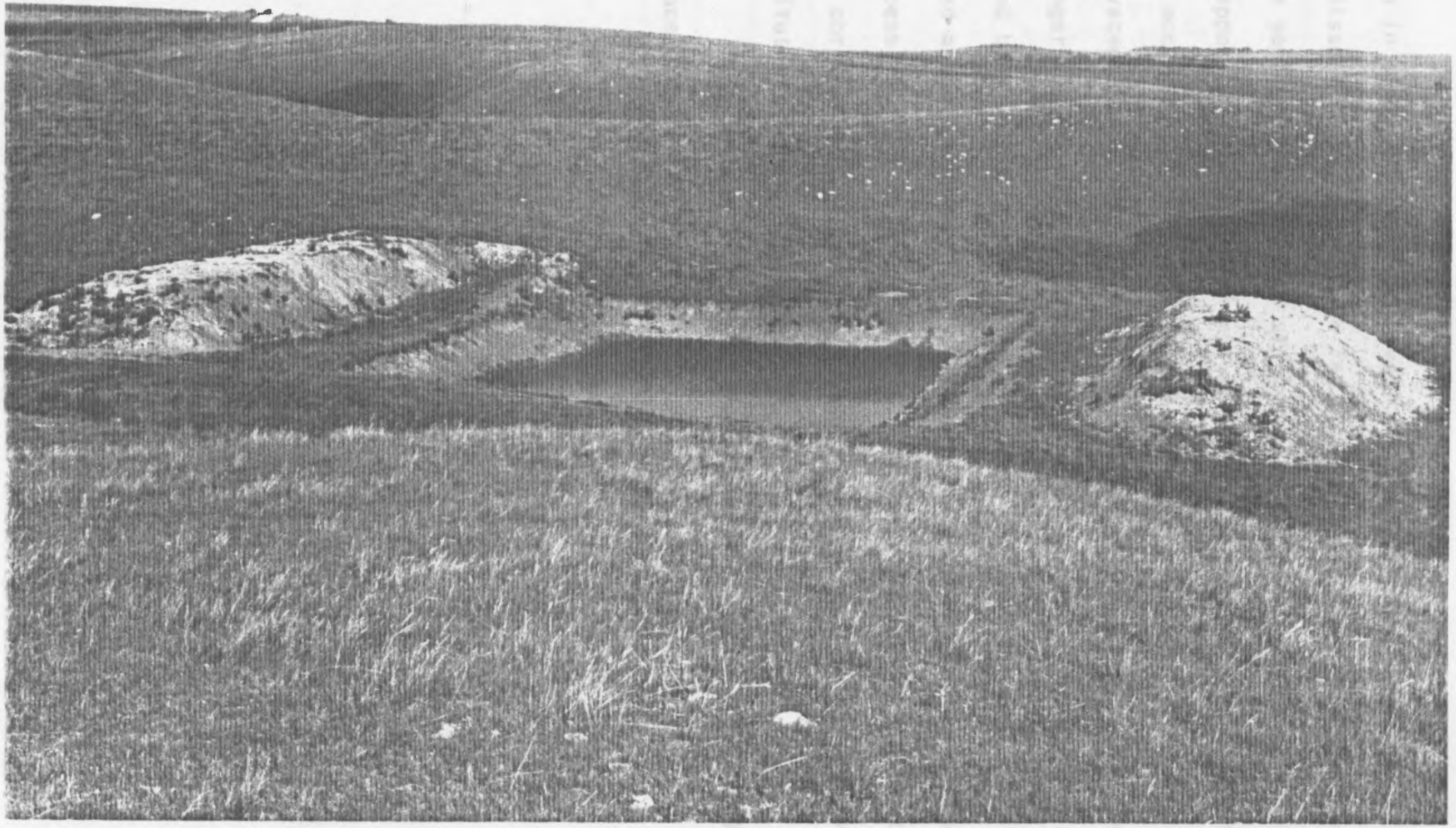

Figure 2. Kurtz dugout, located in Brookings County, typifies the design structure of South Dakota dugout ponds.

depth in ponds designed for livestock is 3.0 m east and 3.7 m west of the Missouri River. For this region, the 2 side slopes and one end slope generally will not be steeper than 2:1 or flatter than 4:1, but the opposite end slope will not be steeper than 4:1. Dimensions may vary according to the nature and stability of the soil material. The excavated material or spoil is placed such that its weight will not endanger the stability of the pond side slopes and where it will not be washed back into the pond by runoff. Spoil banks are usually uniformly placed and shaped along the side slopes. Pond bottom materials consist of loess, silt, clay, and sand. These criteria for pond construction also correspond to standards for excavated ponds in Canada (Freshwater Institute of Canada no date).

Dugouts used during the study period ranged from 0.04-0.08 ha in surface area and from 1.2-3.6 m in maximum depth.

MATERIALS AND METHODS

Rainbow Trout Production

Two experimental designs were employed to evaluate the growth rate of rainbow trout. First, a 4 x 3 factorial design with 4 treatments and 3 replications was used to determine if significant differences existed in lengths and weights of trout due to the 4 stocking densities. Trout stocking densities (3 ponds stocked/density) tested were 1977/ha, 1483/ha, 988/ha and 494/ha. All 12 ponds (Appendix 1) were also stocked with fathead minnows (Pimephales promelas) at a rate of 2471/ha; all ponds were supplementally fed. Following the initial analysis of variance of length and weight, Tukey's Test for unequal observations was used if significant differences were detected (Steel and Torrie 1980). Tukey's procedure is applicable to pairwise comparisons of means and was used to determine where differences existed among stocking densities and sampling dates. The equation used to obtain Tukey's critical value was:

$$w' = q_\alpha (p, fe) s \sqrt{\tfrac{1}{2}\left(\frac{1}{r_i} + \frac{1}{r_j}\right)} \quad \text{(Steel and Torrie 1980)}$$

Second, a 3 x 3 factorial design with 3 treatments and 3 replications was used to determine if significant differences existed in lengths and weights of trout due to treatment combinations. Combinations (3 ponds stocked/combination) tested were trout with fathead minnows and supplemental feed, trout with supplemental feed, and trout alone. All 9 trout ponds (Appendix 1) were stocked at 494/ha for this analysis of variance.

Recruitment from fathead minnow reproduction was intended to provide a potential food for rainbow trout. Structures composed of tree brush (Flickinger 1971) were intermingled with wooden laths and placed in the dugouts to provide minnow reproductive substrate. Minnows were stocked on 17 April 1980 and had a mean total length of 65.4 mm (range = 52-74 mm). Rainbow trout were obtained from the Cleghorn Springs State Fish Hatchery in Rapid City, South Dakota and stocked at the appropriate density on 30 April 1980. Trout were hatched on 19 October 1979. Mean total length and weight at stocking were 139.7 mm and 27.8 g respectively with a total length range of 80-175 mm. Trout mortality associated with hauling stress was monitored for one week after stocking. Dead trout were replaced with live fish maintained in extra dugouts. Stocking mortality observed was 6.9%; in the range of values reported by Johnson et al. (1970).

Supplemental feeding began 3 May 1980 and continued every other day for the first 3 weeks after stocking, after which time ponds were fed only during sampling periods. The purpose of supplemental feeding was to acclimate the trout to a feeding area in hopes of facilitating removal of fish and also to increase trout growth rates. Trout were fed a floating large fingerling size Purina Trout Chow pellet. The food was 37.5% protein and was fed at a rate of 1.0% of fish body weight.

Fish and water chemistry samples were taken at approximately 2-week intervals beginning on 12 May 1980. Fish collections were curtailed after 9 July due to netting stress (Myers and Peterka 1976). Two bag seines (23.0 m x 2.1 m, with 19 mm mesh, and 45.4 m x 4.9 m in the middle, tapering to 2.4 m at both ends, with 19 mm mesh) were used to collect trout. During the sampling periods, a sample of 6 fish was collected by seining half the dugout; the fish were weighed (nearest

1.0 g), measured (nearest 1.0 mm TL), and returned to the pond. During final harvest on 10-11 October 1980, all fish were removed by seining the entire pond. Seining effort ceased when 2 consecutive hauls produced no trout. In 3 dugouts, 2 mg/l rotenone was applied to determine if fish remained after seining; results were used to ascertain seining success.

Stomachs were collected from fish during final harvest by removing the digestive tract anterior to the pyloris (Koth 1980). Stomachs were preserved in 10% formalin; contents were identified (Pennak 1978) and counted in the laboratory. Trout carcasses were cleaned, packed on ice, and distributed to the landowners or were frozen.

Water chemistry parameters were monitored in all trout ponds during the study. Dissolved oxygen, phenolphthalein and total alkalinity, total hardness, and carbon dioxide were measured using a Hach dr-el/l kit. Dissolved oxygen water samples were obtained at surface, middle, and bottom depths using a Kemmerer water bottle sampler. Alkalinity, total hardness, carbon dioxide, and pH were measured near the shoreline. A Hach Model 17-N Wide Range pH test kit was used to measure pH, and values were calibrated by fitting a polynomial regression line to standard and observed pH readings due to the inaccuracy of the kit. Temperature, salinity, and conductivity were measured using a YSI Model 33 S-C-T meter; readings were taken at surface, middle, and bottom depths near the deepest part of the dugout. Conductivity readings were adjusted to and recorded at 25 C. Additional observations concerning algal blooms, cattle usage, and fish feeding behavior were recorded.

Rainbow trout palatability was determined on 22 January 1981 by a 12-member panel in the Food Science Department, South Dakota State

University. Fish from 3 dugouts were thawed for 24 hours, washed in cold water, dipped in Crisco salad oil, and baked at 204.4 C for 20-25 minutes. Fillets were skinned, flaked, and served warm. The panel judged each sample according to color, odor, flavor, texture, and appearance categories. Chi-square analysis using a 2-way contingency table examined individual reactions to categories between ponds.

Annual Cycle of Chemical-Physical Properties

Chemical-physical properties (Table 1) were monitored and compared between a 3-year old (Oppelt) and 1-year old (Kurtz) dugout from July 1980 to July 1981 (Appendix 2). Morning samples were taken at approximately 2-week intervals for water analysis. Three stations were selected along a diagonal cross section in each pond (Oppelt stations from SW to NE direction and Kurtz stations from NW to SE direction). Station 1 was located at the maximum pond depth, Station 2 at half the maximum depth, and Station 3 at 0.5 m. Sampling Station 3 in the Oppelt dugout was discontinued 22 March 1981 due to the declining pond depth and interference with Station 2.

Dissolved oxygen was measured at 0.5 m depth intervals at each station. Due to the water sampler design, the last oxygen sample was taken at the nearest 0.5 m interval from the pond bottom. All water samples were collected by a 2.2 L Kemmerer Plus PVC bottle. During ice cover, oxygen measurements at the surface and Station 3 were discontinued. Dissolved oxygen samples were collected in 300 ml glass BOD bottles, prepared with the first 2 reagents, and returned to the laboratory for titration and determination.

Table 1. Chemical-physical procedures for parameters measured in Kurtz and Oppelt dugouts, July 1980 to July 1981.

Parameter	Procedure
Temperature	Yellow Springs Instrument S-C-T Meter Model 33
Salinity	Yellow Springs Instrument S-C-T Meter Model 33
Specific Conductance	Yellow Springs Instrument S-C-T Meter Model 33
Visibility	Secchi Disc
Turbidity	Jackson Candle Turbidimeter
pH	Hach Model 17-N Wide Range pH Test Kit
Dissolved Oxygen	Azide Modification Method
Free Carbon Dioxide	Titrimetric Method
Total Alkalinity	Mixed Bromcresol Green-Methyl Red Indicator Method
Carbonate	Calculation
Bicarbonate	Calculation
Total Hardness	Calculation from Ca, Mg, Fe, Mn
Carbonate	Equals Total Alkalinity
Noncarbonate	Total Hardness - Total Alkalinity Calculation
Calcium	EDTA Titrimetric Method
Magnesium	Hardness - Calcium Calculation
Iron	Phenanthroline Method
Manganese	Atomic Absorption Spectrophotometric Method
Phosphate	
Ortho-	Stannous Chloride Method
Total	Persulfate Digestion - Stannous Chloride Method
Nitrate-N	Brucine Method
Ammonia-N	Nesslerization Method
Chloride	Mercuric Nitrate Method
Potassium	Atomic Absorption Spectrophotometric Method
Sulfate	Turbidimetric Method
Sodium	Atomic Absorption Spectrophotometric Method

Carbon dioxide, pH, and alkalinity were measured in the field at Station 1. Carbon dioxide was determined from a middle water sample depth; pH from a surface water sample, and alkalinity from a composite (surface, middle, bottom) water sample. Parameters (turbidity, calcium, magnesium, iron, manganese, ortho- and total phosphate, nitrate-N, ammonia-N, chloride, potassium, sulfate and sodium) to be determined in the laboratory were obtained by sub-sampling a composite sample at Station 1. All water samples were packed in an ice filled chest and transported to the laboratory for further analysis.

Temperature, salinity, and conductivity were measured at 0.5 m depth intervals at each station. Secchi disc visibility was determined to give an index of water clarity. A 3 hp, 2-cycle Jiffy ice auger aided in drilling holes through the ice.

Water sample procedures (Table 1) followed the American Public Health Association (1975). Calcium, magnesium, iron, manganese, ortho- and total phosphate, nitrate-N, ammonia-N, chloride, potassium, sulfate, and sodium were determined by the Water Quality Lab, Agricultural Engineering Department, South Dakota State University. Conductivity was adjusted to and recorded at 25 C and pH was calibrated. Carbonate and bicarbonate fractions of alkalinity were calculated from phenolphthalein and total alkalinity. Total hardness was calculated from Ca, Mg, Fe, and Mn ions and expressed as calcium carbonate.

RESULTS AND DISCUSSION

Trout Growth, Density, and Survival

Evaluation of rainbow trout growth, as related to the various stocking densities, was based on 4 sampling periods from May to July, 1980. The cessation of sampling was a result of high surface water temperatures which appeared harmful to rainbow trout survival.

Analysis of variance indicated highly significant ($P < .01$) differences in weights and lengths of rainbow trout at the various stocking densities (Table 2-3). Significant differences also existed in weights ($P < .01$) and lengths ($P < .05$) of trout due to the interaction of density levels and sampling periods. During the 21-23 May 1980 collections, mean weights (Fig. 3) and lengths (Fig. 4) of trout at the various stocking rates were 49.7 g and 165.3 mm (1977/ha), 45.3 g and 159.4 mm (1483/ha), 68.2 g and 178.9 mm (988/ha), and 58.9 g and 168.7 mm (494/ha). The 988/ha density was significantly ($P < .05$) greater in weight and length than the 1483/ha density, but not significantly ($P > .05$) different from the other densities (Table 4 and Table 5). During the 6-7 June 1980 collections, mean weights and lengths of trout at the various stocking rates were 54.4 g and 171.1 mm (1977/ha), 49.9 g and 167.7 mm (1483/ha), 84.3 g and 192.1 mm(988/ha), and 58.9 g and 179.3 mm (494/ha). The 988/ha density was significantly ($P < .05$) greater in weight and length than 1977/ha and 1483/ha, but not different from 494/ha. The 494/ha stocking rate was not different ($P > .05$) from either the 1977/ha or 1483/ha rates. During the 20-25 June 1980 collections, mean weights and lengths of trout at the various stocking rates were 65.5 g and 179.0 mm

Table 2. Analysis of variance of rainbow trout (*Salmo gairdneri*) weight due to stocking rate and date in 12 South Dakota dugouts, 1980.

Source of variation	Degrees of freedom	Mean square	F
Stocking rate	3	25927.3	43.0 **
Date	3	6954.6	11.53**
Stocking rate x date	8	3089.8	5.12**
Error	190	603.1	

**Significant at .01 level of probability.

Table 3. Analysis of variance of rainbow trout (*Salmo gairdneri*) total length due to stocking rate and date in 12 South Dakota dugouts, 1980.

Source of variation	Degrees of freedom	Mean square	F
Stocking rate	3	10472.6	30.17**
Date	3	4896.8	14.11**
Stocking rate x date	8	853.8	2.46*
Error	190	347.2	

* Significant at .05 level of probability.

**Significant at .01 level of probability.

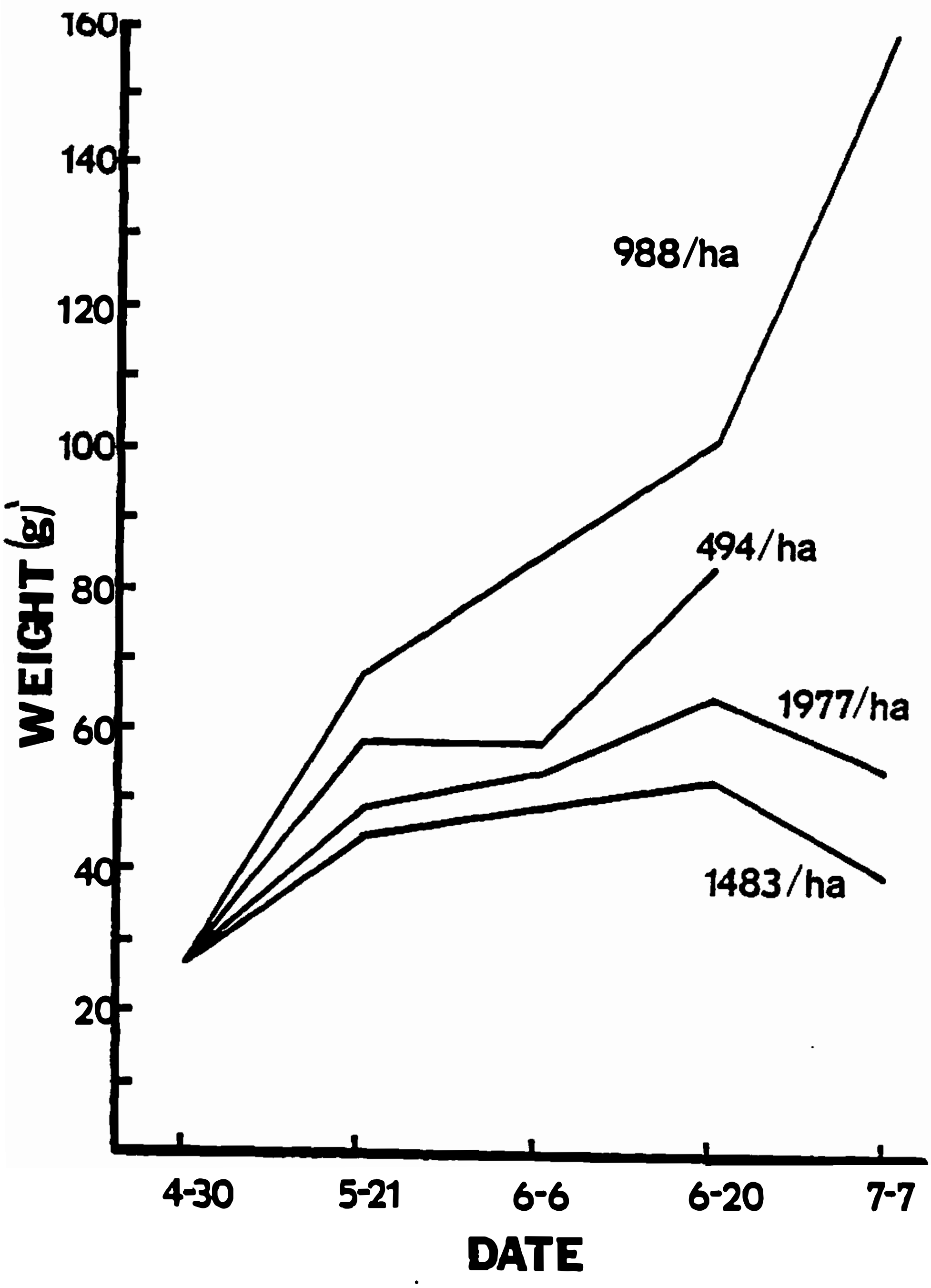

Figure 3. Mean weight (g) of rainbow trout (Salmo gairdneri) at various stocking densities for sampling dates in South Dakota dugouts, 1980.

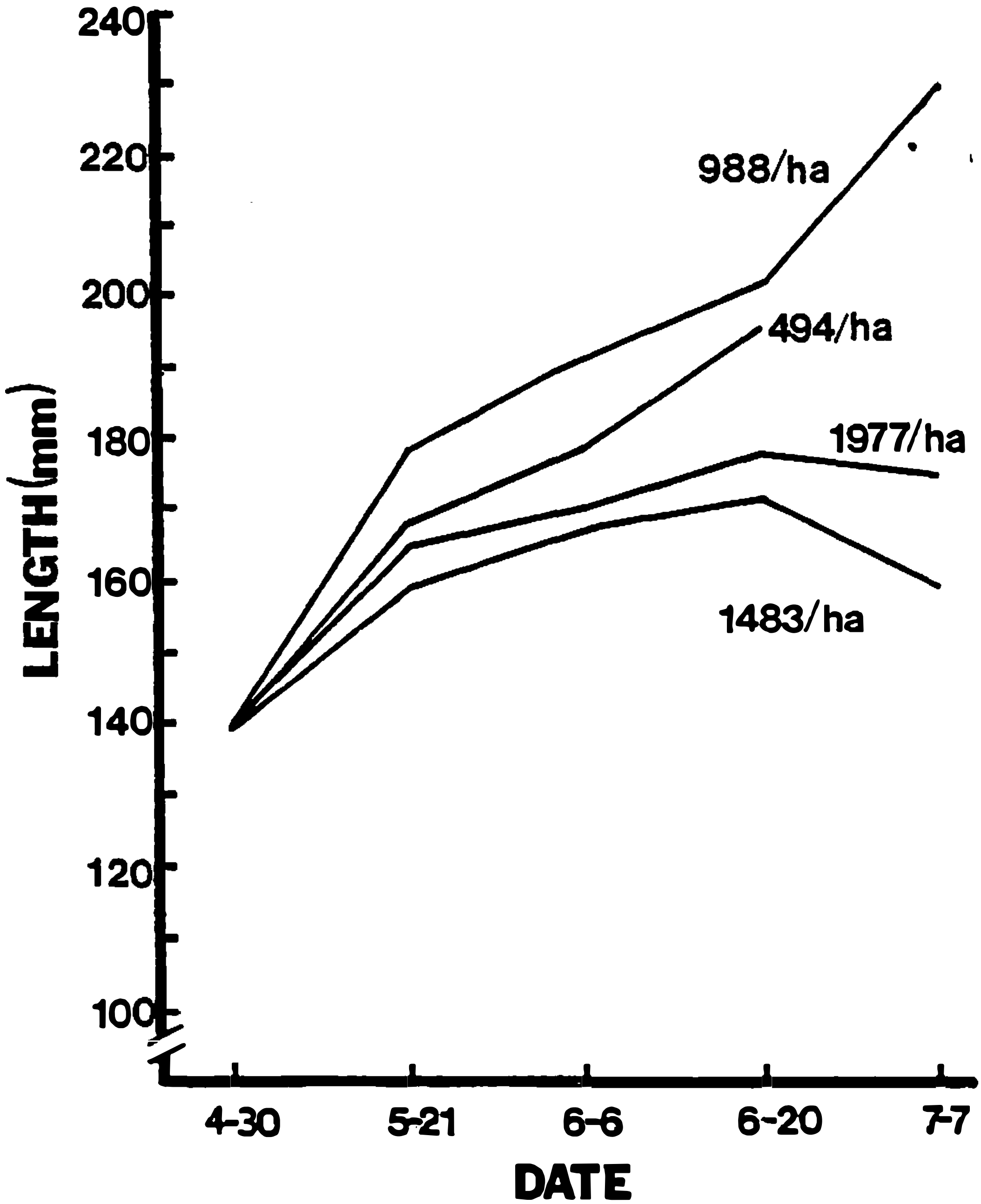

Figure 4. Mean length (mm) of rainbow trout (Salmo gairdneri) at various stocking densities for sampling dates in South Dakota dugouts, 1980.

Table 4. Tukey's test for unequal observations to determine differences in rainbow trout (*Salmo gairdneri*) mean weight between stocking rates by dates, 1980.

Tukey's critical value $w' = q_{\alpha}\ (p, fe)s$

$s = \sqrt{603.03} = 24.556$

Value of q_{α}

4 treatment means = 3.63
3 treatment means' = 3.31

5-21-1980

	494/ha	988/ha	1483/ha	1977/ha
# Observations	14	18	18	18
Mean	58.9	68.2	45.3	49.7

Comparison	Critical Value
1977/ha - 494/ha = 9.26	22.46
1977/ha - 988/ha = 13.60	21.01
1977/ha - 1483/ha = 9.29	21.01
1483/ha - 494/ha = 18.56	22.46
1483/ha - 988/ha = 22.89*	21.01
988/ha - 494/ha = 4.33	22.46

6-6-1980

	494/ha	988/ha	1483/ha	1977/ha
# Observations	7	16	18	18
Mean	58.9	84.3	49.9	54.4

Comparison	Critical Value
1977/ha - 494/ha = 4.47	28.08
1977/ha - 988/ha = 29.86*	21.66
1977/ha - 1483/ha = 4.44	21.01
1483/ha - 494/ha = 8.91	28.08
1483/ha - 988/ha = 34.31*	21.66
988/ha - 494/ha = 25.39	28.56

Table 4. Continued.

6-20-1980

	494/ha	988/ha	1483/ha	1977/ha
# Observations	15	13	16	18
Mean	84.0	101.9	53.9	65.5

Comparison	Critical Value
1977/ha - 494/ha = 18.5	22.04
1977/ha - 988/ha = 36.42*	22.94
1977/ha - 1483/ha = 11.56	21.66
1483/ha - 494/ha = 30.06*	22.65
1483/ha - 988/ha = 47.99*	23.54
988/ha - 494/ha = 17.92	23.88

7-7-1980

	494/ha[2]	988/ha	1483/ha	1977/ha
# Observations	---	6	4	6
Mean	---	158.5	40.3	55.5

Comparison	Critical Value
1977/ha - 988/ha = 103.0*	33.18
1977/ha - 1483/ha = 15.25	37.10
1483/ha - 988/ha = 118.25*	37.10

* Significant at .05 level of probability.

[1] 3 means tested 7-7-1980.

[2] No fish collected.

Table 5. Tukey's test for unequal observations to determine differences in rainbow trout (Salmo gairdneri) mean total length between stocking rates by dates, 1980.

Tukey's critical value $w' = q_{\alpha}\ (p,fe)s$

$s = \sqrt{347.15} = 18.63$

Value of q_{α}

4 treatment means = 3.63
3 treatment means' = 3.31

5-21-1980

	494/ha	988/ha	1483/ha	1977/ha
# Observations	14	18	18	18
Mean	168.7	178.9	159.4	165.3

Comparison	Critical Value
1977/ha - 494/ha = 3.44	17.04
1977/ha - 988/ha = 13.61	15.94
1977/ha - 1483/ha = 5.83	15.94
1483/ha - 494/ha = 9.27	17.04
1483/ha - 988/ha = 19.44*	15.94
988/ha - 494/ha = 10.17	17.04

6-6-1980

	494/ha	988/ha	1483/ha	1977/ha
# Observations	7	16	18	18
Mean	179.3	192.1	167.7	171.1

Comparison	Critical Value
1977/ha - 494/ha = 8.23	21.30
1977/ha - 988/ha = 21.07*	16.43
1977/ha - 1483/ha = 3.39	15.94
1483/ha - 494/ha = 11.62	21.30
1483/ha - 988/ha = 24.46*	16.43
988/ha - 494/ha = 12.84	21.67

Table 5. Continued.

6-20-1980

	494/ha	988/ha	1483/ha	1977/ha
# Observations	15	13	16	18
Mean	196.5	203.0	172.3	179.0

Comparison	Critical Value
1977/ha - 494/ha = 17.47*	16.72
1977/ha - 988/ha = 24.0*	17.41
1977/ha - 1483/ha = 6.69	16.43
1483/ha - 494/ha = 24.15*	17.19
1483/ha - 988/ha = 30.69*	17.86
988/ha - 494/ha = 6.53	18.12

7-7-1980

	494/ha[2]	988/ha	1483/ha	1977/ha
# Observations	---	6	4	6
Mean	---	230.3	160.5	176.3

Comparison	Critical Value
1977/ha - 988/ha = 54.0*	25.18
1977/ha - 1483/ha = 15.83	28.15
1483/ha - 988/ha = 69.83*	28.15

* Significant at .05 level of probability.

[1] 3 means tested 7-7-1980.

[2] No fish collected.

(1977/ha), 53.9 g and 172.3 mm (1483/ha), 101.9 g and 203.0 mm (988/ha), and 84.0 g and 196.5 mm (494/ha). Both 988/ha and 494/ha were significantly ($P < .05$) greater in length than 1977/ha and 1483/ha, but only 988/ha was significantly greater in weight than 1977/ha and 1483/ha. No differences were detected between 1977/ha and 1483/ha. The significant increase in length and nonsignificant change in weight when compared to 1977/ha and 1483/ha densities may imply an increase in conditions of trout at 494/ha. The probable change in condition was because the dugout with best growth for the 494/ha density was not sampled due to flooding during the 6-7 June 1980 collections (Appendix 3). During the 7-10 July 1980 collections, mean weights and lengths of trout at the various stocking rates were 55.5 g and 176.3 mm (1977/ha), 40.3 g and 160.5 mm (1483/ha), and 158.5 g and 230.3 mm (988/ha). No rainbow trout were collected from the 494/ha dugouts. The 988/ha density fish were significantly ($P < .05$) greater in weight and length than the fish in the 1977/ha and 1483/ha dugouts. It appeared that trout decreased in weight and length for 1977/ha and 1483/ha densities and increased for 988/ha (Fig. 3-4). The unusual decreases may be explained by few fish in the collections and only one dugout representing the means for each stocking rate. The fish were collected from dugouts exhibiting poorer growth rates.

Higher stocking densities did as well or better in relation to condition factors (Table 6) than the lower densities during sampling periods. No statistical analysis was justified due to the variability in fish collected between dugouts. All trout increased in condition from initial stocking $\left[K(TL) = 1.02\right]$ to the first sampling after stocking. The higher density trout stockings tended to decrease in condition as the

Table 6. Condition factors, K (TL), of rainbow trout (*Salmo gairdneri*) using the mean length and weight of fish for each density level during each sampling period, 1980.

Date	Stocking Density			
	494/ha	988/ha	1483/ha	1977/ha
5/21 - 23/80	1.23	1.19	1.12	1.10
6/6 - 7/80	1.02	1.19	1.06	1.09
6/20 - 25/80	1.11	1.22	1.05	1.14
7/7 - 10/80	a	1.30	0.97	1.01

[a] No trout collected in samples.

season progressed, while lower densities tended to increase. It should be noted that during the July sample, no trout were collected from some dugouts, thus condition factors may be biased. Needham and Slater (1945) reported that rainbow trout in Convict Creek, California showed a decrease in condition in May to July. The relatively low trout population levels seemed to be conducive to faster growing fish in terms of length and weight rather than what condition factors may indicate when consideration is given to the duration of the growing season, available food supply, and suitable temperature and oxygen.

Growth was greater for 988/ha rainbow trout than other stocking densities and is comparable with growth in other areas of the country. Weight and length gains of 130.7 g and 90.6 mm, respectively, for dugout rainbow trout were greater than values attained by Myers and Peterka (1976) in North Dakota lakes at 500/ha rainbow trout for approximately similar growth periods. Dugout rainbow trout at 988/ha had a mean weight of 158.5 g, which was comparable to Alabama ponds, but Tatum (1976) had attained his values at densities of 6250/ha and 3750/ha with supplemental feeding twice daily six days a week. At 9 months of age, 988/ha dugout rainbow trout had a mean weight and length of 158.5 g and 230.3 mm. Data accumulated by Carlander (1969) indicated that these means were within the range of means of western United States lakes for rainbow trout over age-I or 12 months of age. Lawler et al. (1974) reported that in Canadian lakes stocking rates had little apparent effect on final size of trout at planting rates below 2500/ha without supplemental feeding.

Of the 957 rainbow trout stocked in the study ponds, 25 were recovered during the final harvest; a 2.6% survival rate. The mean weights and lengths (Appendix 4) of the fish collected were 114.8 g (range = 55 to 272 g) and 213.0 mm (range = 172 to 289 mm). Survival was below the values of 84% and 92% recorded by Reagan and Robinette (1975) for Mississippi winter pond culture of rainbow trout. Previous annual studies by Jensen (1979) reported a survival range of 90.5 to 96.8% for ponds in Alabama, while Tatum (1976) recorded a survival range of 22.8 to 53.6% for Alabama ponds. Myers and Peterka (1976) studied 4 prairie lakes in North Dakota and found a range of survival of 0.0 to 4.4% by the October harvest. During this study, it would appear that the greatest mortality of rainbow trout in dugouts occurred between July and October.

Numerous possible causes contributed to mortality of rainbow trout during this study. Plausible causes were fluctuations in water levels, oxygen and temperature limits, algal blooms and collapse, observed turbidity associated with cattle usage, competition, predation, handling stress, and delayed stocking mortality.

One of the possible causes of mortality was the fluctuations in water levels which reduced the habitable water zone for rainbow trout. Depth was not adequate to prevent lethal conditions concerning dissolved oxygen and temperature. Summer mortality of rainbow trout prevails when dissolved oxygen falls below 6 mg/l (Barica 1975; Ayles et al. 1976) and water temperature approaches 27 C (Cherry et al. 1977). The maximum water level varied from 1.2-3.6 m during the study (Appendix 5). The mean depth for all dugouts during 7-10 July 1980 sampling, when relatively few trout were collected in the seine hauls, was 2.7 m. Mean dissolved oxygen and temperature for top, middle, and bottom samples were 8.9 mg/l, 6.5 mg/l, and 2.7 mg/l, respectively, and 27.3 C, 23.1 C, and 19.9 C, respectively. Surface temperatures as high as 34.2 C were recorded and 15 out of 18 dugouts had bottom dissolved oxygen levels below 4.0 mg/l. Dissolved oxygen and temperature lethal limits could be avoided by rainbow trout if adequate water depth were available in the ponds, or if oxygenation of the pond bottom were employed (Overholtz et al. 1977).

Several dugouts had algal blooms which collapsed; this produced oxygen depletion near the bottom because of decomposition of the algae. *Microcystis* and *Volvox* were identified as major contributors to the algal blooms. Increases in pH, carbon dioxide, and carbonate alkalinity, associated with algal blooms and collapse, approached lethal limits for rainbow trout (Witschi and Ziebell 1979). Ranges in values were; pH from 7.35-9.17, carbon dioxide from 0-24 mg/l, and carbonate alkalinity from 0-120 mg/l. Range values were comparable to those reported by Schmidt (1967) and Gloss (1969) for surrounding lakes.

Mortality of rainbow trout in small eutrophic lakes of central Canada has generally been attributed to blooms and collapses of the blue-green algae *Aphanizomenon flos-aqua* (Lawler et al. 1974; Ayles et al. 1976). Barica (1973; 1975) and Ayles and Barica (1977) proposed that by monitoring winter NH_3-N, summer chlorophyll a, and summer specific conductance prior to stocking trout, summerkill could be predicted. Lakes with winter NH_3-N exceeding 1000 µg/l, summer chlorophyll a exceeding 100 µg/l, and summer specific conductance in the range of 800 - 2000 µmhos/cm had high summer-kill risk. By monitoring these variables in dugouts prior to rainbow trout stocking, dugouts with lower risk of algal blooms could be predicted.

Another problem influencing trout survival was increased turbidity associated with livestock watering. Dugouts are placed in pastures primarily for livestock watering and distribution of grazing pressure. Under high livestock index conditions, turbidity increased due to cattle wading into the dugout. In order to improve trout survival and production, particularly during periods of increasing temperatures, limiting cattle access by fencing is recommended.

Competition and predation were not observed in any dugouts, but could be a problem associated with trout mortality. Contaminating fishes, cormorants, herons, salamanders, and turtles occurred in many dugouts and have posed problems in other areas of the country (Myers and Peterka 1976; Fraser 1978; McCaig 1980). Contaminating fishes occurring in 5 dugouts were the black bullhead (*Ictalurus melas*), brook stickleback (*Culaea inconstans*), carp (*Cyprinus carpio*), green sunfish (*Lepomis cyanellus*), white sucker (*Catostomus commersoni*), and yellow perch (*Perca flavescens*). Fathead minnows and contaminating fishes were observed taking the prepared food intended for trout and may also have competed for natural foods. Salamanders are prevalent in many South Dakota waters as well as North Dakota waters (Myers 1973); the extent to which they compete with or prey upon young trout is unknown.

Mortality cannot be attributed to any single cause, but a combination of all those discussed may have resulted in poor survival of rainbow trout. Due to the high incidence of mortality, it is believed that the optimal stocking density or production of rainbow trout was not totally determined.

Feeding Behavior

In order to determine if the presence or absence of fathead minnows and/or supplemental trout feed effected the growth of rainbow trout, an analysis of variance was performed. No significant differences ($P > .05$) were found to exist among treatments (Table 7-8). It could be concluded that there is insufficient evidence to state that fathead minnows and supplemental feeding at 1.0% fish body weight enhanced growth of rainbow trout. Mean weight and length data for rainbow trout and feeding combination are presented in Table 9. The increase in weight and length for the trout and supplemental feeding combination in July was higher than expected; one rainbow trout was sampled from 3 dugouts to represent the mean value. There appeared to be a decrease in weight and length for the trout alone combination from late June to July sampling dates. Fish have continuous growth and the apparent decrease occurred primarily because 1 dugout representing a large proportion of the average of 3 dugouts during the June sampling produced no trout during the July sampling.

Implications that rainbow trout grew better when stocked alone instead of with minnows and/or supplemental feed tends to be misleading. Feeding the trout was primarily intended to lure the fish to an area of the pond to facilitate removal; growth was also to be enhanced. Rainbow trout did not actively take the feed. Sporadic surface feeding by trout did occur, but possible causes for less vigorous feeding habits could have been pond turbidity; rainbow trout are obligate visual feeders (Ware 1972), reduced utilization time due to washing of feed onto the pond banks prior to trout consumption (Ware 1972), and minnows feeding at the trout feed when the feed was thrown onto the pond surface.

Table 7. Analysis of variance of rainbow trout (*Salmo gairdneri*) weight to determine if the presence or absence of fathead minnows (*Pimephales promelas*) and supplemental feed affected weight of trout in 9 South Dakota dugouts, 1980.

Source of variation	Degrees of freedom	Mean square	F
Treatment	2	581.9	1.05
Date	3	6514.4	11.82**
Treatment x date	5	718.3	1.30
Error	107	551.1	

**Significant at .01 level of probability.

Table 8. Analysis of variance of rainbow trout (*Salmo gairdneri*) total length to determine if the presence or absence of fathead minnows (*Pimephales promelas*) and supplemental feed affected length of trout in 9 South Dakota dugouts, 1980.

Source of variation	Degrees of freedom	Mean square	F
Treatment	2	126.4	0.48
Date	3	4621.2	17.7 **
Treatment x date	5	473.8	1.82
Error	107	261.0	

**Significant at .01 level of probability.

Table 9. Mean weight and length data of rainbow trout (*Salmo gairdneri*) from feeding combinations with/without fathead minnows (*Pimephales promelas*) and supplemental feed in 9 South Dakota dugouts, 1980.

Date:	5-21		6-6		6-20		7-7	
Combination	weight	length	weight	length	weight	length	weight	length
Rainbow trout/ Supplemental feed/ Fathead minnows	58.9	168.7	58.9	179.3	84.0	196.5	a	
Rainbow trout/ Supplemental feed	58.3	167.2	79.9	190.6	83.3	183.3	123.0	228.0
Rainbow trout alone	53.7	168.2	71.5	183.8	100.1	201.5	95.5	194.3

[a] No rainbow trout collected in the seine hauls.

By observation, fathead minnows may have been detrimental to rainbow trout growth and survival through competition for feed. Even though a size difference existed between the 2 species, minnows fed more readily than rainbow trout. Similar conclusions were stated by Burdick and Cooper (1956) for rainbow trout fingerlings in Weber Lake, Wisconsin. Since rainbow trout were not sacrificed until the final harvest date for stomach content analysis, the utilization of minnows by trout during sampling periods is unknown. Koth (1980) found fathead minnows to comprise 1.2% by number/stomach and 16.8% by volume/stomach in 159 rainbow trout stomachs in South Dakota.

Stomach samples were taken during the 10-11 October 1980 harvest dates and stomach contents were determined for 29 rainbow trout. Each organism was enumerated as to percent number per stomach, percent volume per stomach, and frequency of occurrence. Stomachs contained a total number of 1958 food organisms with a total volume of 42.15 ml.

Rainbow trout stomachs contained almost exclusively insects, 99.4% by number and 93.5% by volume (Table 10). Chironomidae comprised the most numerically abundant (42.6%) of organisms in the trout diet; corixids ranked second (32.3%), notonectids third (16.5%), and chaoborids fourth (4.2%).

Corixids comprised the largest volume (50.6%) of food organisms with notonectids ranked second (21.4%), chironomids third (12.9%), and dytiscids fourth (2.0%).

Insects were also found to be the most abundant numerically (96.6%) and volumetrically (63.5%) by Koth (1980) from 159 rainbow trout stomachs in a South Dakota prairie pond. Myers (1973) found that insects were the

Table 10. Stomach contents of rainbow trout (*Salmo gairdneri*) from harvested dugouts, October, 1980, expressed as percent number per stomach and percent volume per stomach (in parentheses). (T=trace)

	Dugout					
Food Item	Gullickson	Matson	Nissen	Sutton	Svennes	Workman
Amphipoda						2.5 (T)
Coleoptera						
Dytiscidae	6.7 (33.3)		T (1.7)	T (T)	8.1 (11.5)	T (2.8)
Haliplidae	80 (33.3)				8.1 (1.6)	T (T)
Hydrophilidae					1.4 (1.8)	
Diptera						
Chaoborinae			7.9 (T)			
Chironomidae			74.4 (41.3)	12.9 (3.8)	1.4 (T)	
Hemiptera						
Belostomatidae			T (4.7)			
Corixidae	6.7 (20.0)	50.0 (3.8)	16.2 (46.4)	83.6 (91.5)	50.0 (74.3)	11.2 (4.9)
Notonectidae		16.7 (1.9)	T (T)	2.6 (3.7)	4.1 (4.6)	83.9 (78.5)
Odonata						
Anisoptera						T (10.9)
Zygoptera	6.7 (13.3)			T (T)	27.0 (6.0)	T (T)
Terrestrial Insects			T (3.4)	T (T)		T (1.9)
Fishes						
Fathead minnow			T (2.1)			
Brook stickleback		33.3 (94.3)				
Sample size	1	1	12	9	2	4
No. fish w/food in stomach	1	1	12	9	2	4
Avg. no. food items/stomach	15	6	86.8	50.7	37.0	91.5
Avg. vol. food items(ml)/stomach	.15	2.65	.98	1.65	1.09	2.63

most abundant numerically (54.4%) and volumetrically (64.8%) with amphipods and limnetic crustaceans comprising the remainder of the 153 rainbow trout stomachs in North Dakota pothole lakes. Wurtsbaugh and Brocksen (1975) reported that insects comprised 7.8% by number and 85.2% by volume in 136 rainbow trout stomachs in Castle Lake, California; with the remainder composed of limnetic crustaceans. Carline et al. (1976) reported that insects comprised 31.9% by number of the food in 51 rainbow trout stomachs in a Wisconsin spring pond; with the remainder composed of fish and limnetic crustaceans.

Fathead minnows represented trace amounts of the total number and total volume of organisms consumed. The utilization of fathead minnows by rainbow trout may have been greater if stomachs were collected throughout the study instead of only during the final harvest period. It is also possible that fathead minnows would become a more important diet component if the trout were larger. Larkin and Smith (1954) found that the volume of food in the stomachs was larger and the growth of the trout, after age II, was greater after the redside shiner (*Richardsonius balteatus*) became abundant; growth of younger trout was slowed by the shiner introduction.

Palatability

Chi-square analysis (Table 11) indicated no significant differences ($P > .05$) in the individual reactions to rainbow trout palatability between the 3 dugouts tested in relation to color, odor, texture, or appearance. Seventy-five percent of the individual reactions rated rainbow trout color as fair or better, 69.4% rated odor as fair or better, 50.0% rated texture as good, and 58.3% rated appearance as good or better.

Table 11. Chi-square analysis for rainbow trout (*Salmo gairdneri*) palatability from 3 South Dakota dugouts, 1980.

	Below Fair	Fair	Below Good Above Fair	Good	Above Good	χ^2
COLOR						
Sutton	1	2	1	5	3	10.65
Workman	1	4	5	1	1	
Nissen	0	5	1	3	3	
ODOR						
Sutton	1	1	2	6	2	13.85
Workman	4	4	3	1	0	
Nissen	1	3	0	5	3	
FLAVOR						
Sutton	0	3	2	4	3	18.52*
Workman	8	2	2	0	0	
Nissen	2	2	1	3	4	
TEXTURE						
Sutton	0	3	2	5	2	6.13
Workman	2	1	2	6	1	
Nissen	0	2	1	7	2	
APPEARANCE						
Sutton	2	1	2	6	1	6.00
Workman	2	2	3	3	2	
Nissen	2	0	1	5	4	

* Significant at .05 level of probability.

df = 8.

It should be remembered that the rainbow trout were prepared and cooked with no seasoning.

Significant differences ($P < .05$) were detected in the individual reactions to rainbow trout palatability concerning flavor, with the Workman dugout being different from the other 2 ponds. Eight of 12 panelists (66.7%) felt the Workman rainbow trout were below fair in flavor, which may have been due to the high phytoplankton abundance noticed in that dugout during harvest. Muddy or musty flavor has been noticed in other areas (Lawler et al. 1974; Hahn 1974) and poses a problem to the commercial production of rainbow trout. Lawler et al. (1974) felt the problem of poor flavor could be lessened by leaving rainbow trout in colder water for a longer period until the phytoplankton abundance declined.

Annual Chemical-Physical Properties

An annual cycle of chemical-physical properties was monitored on 2 dugouts, Kurtz (new pond) and Oppelt (older pond) (Appendix 2), to determine seasonal changes and differences. Figures 5 through 8 represent the annual oxygen and temperature profiles for the 2 dugouts. Values were obtained by taking the mean across stations by depth (Appendix 6) during the study period; this was done because little variation occurred between stations at similar depths.

Dissolved oxygen in both dugouts, measured in the morning, attained maximum concentrations during the winter months under ice cover and minimum concentrations during the spring and summer months (20 July 1980 - 6 July 1981 sampling period). The mean maximum and minimum surface oxygen concentrations were 17.8 mg/l (under ice cover) on 18 January 1981 and 7.2 mg/l on 20 July 1980 for the Kurtz dugout, and 26.5 mg/l (under ice cover) on 6 January 1981 and 4.1 mg/l on 20 July 1980 for the Oppelt dugout.

Oxygen concentrations increased with decreasing temperature. From 20 July 1980 to 6 October 1980 (Figure 5), surface oxygen increased from 7.2-10.3 mg/l and temperature decreased 22.1-15.5 C in the Kurtz dugout. Surface oxygen increased from 4.1-9.6 mg/l and temperature decreased from 22.2-14.8 C in the Oppelt dugout. Oxygen reached a level of 13.0 mg/l on 12 August, which could be attributed to a phytoplankton bloom. From 20 October 1980 to 6 January 1981 (Fig. 6), surface oxygen increased from 11.7-17.7 mg/l and temperature decreased from 7.9-3.8 C in Kurtz. Surface oxygen increased from 10.7-26.5 mg/l and temperature decreased from 8.2-3.0 C in Oppelt. From 18 January

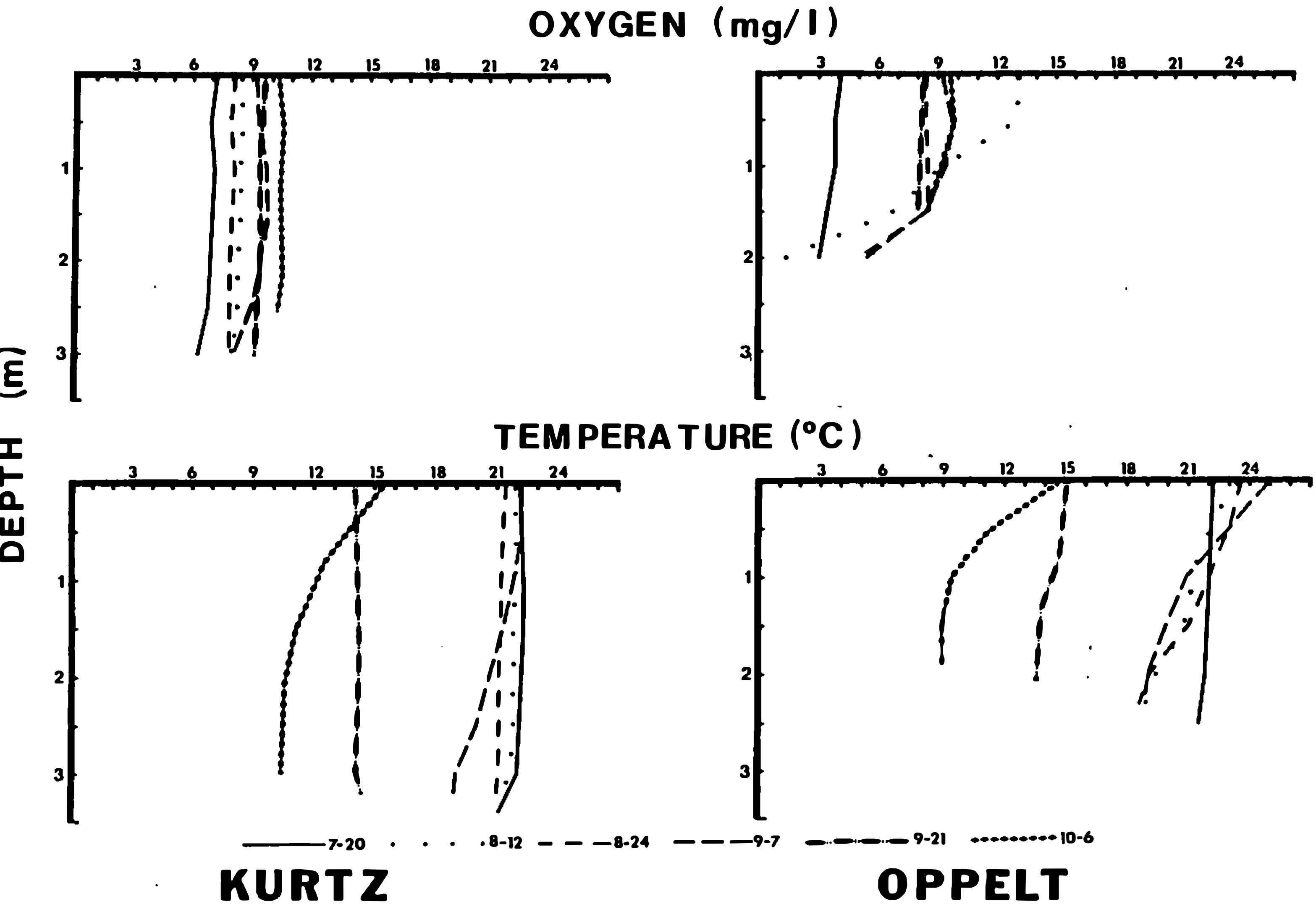

Figure 5. Mean dissolved oxygen and temperature profiles across stations by depth of Kurtz and Oppelt dugouts for 20 July 1980 to 6 October 1980.

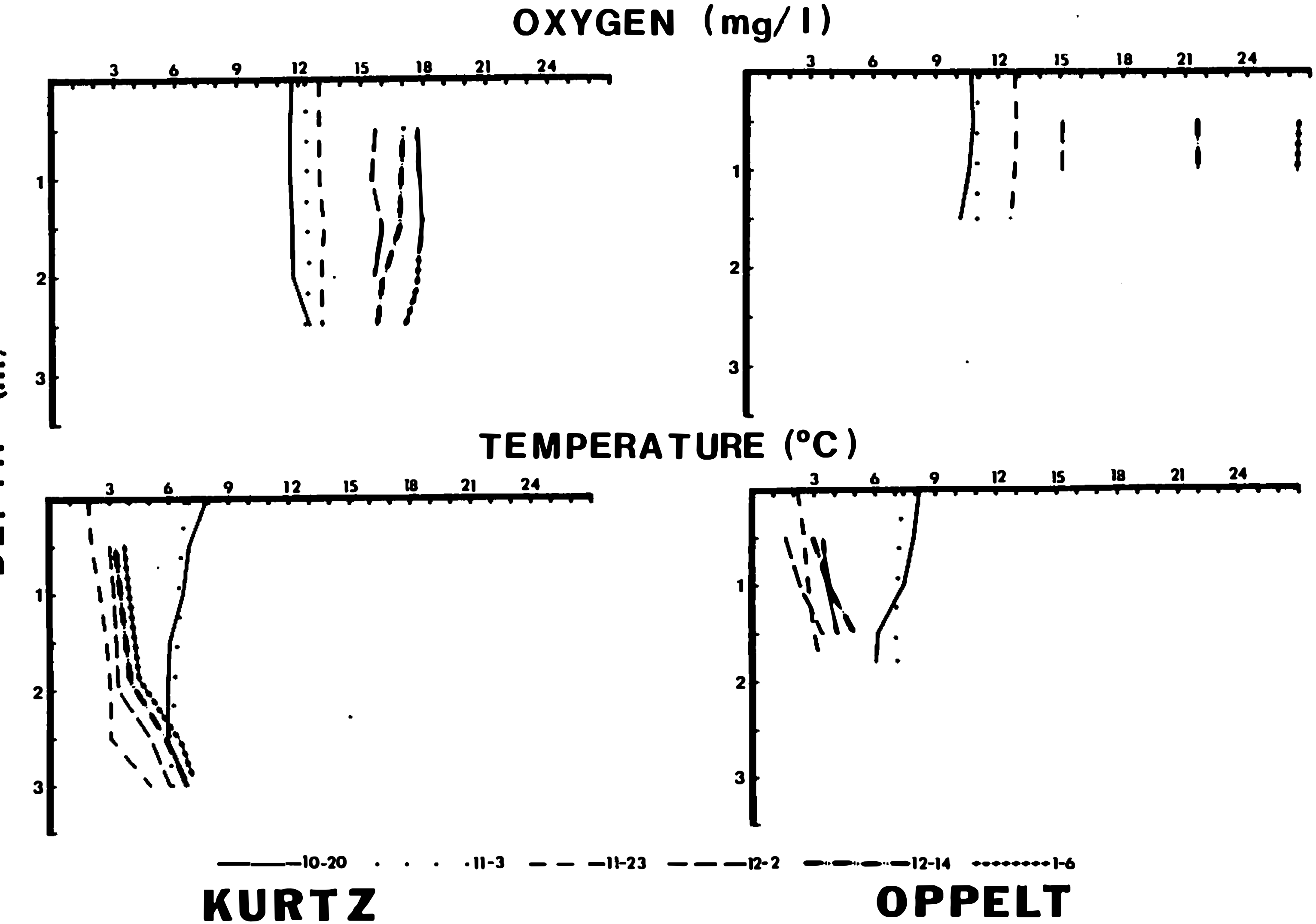

Figure 6. Mean dissolved oxygen and temperature profiles across stations by depth of Kurtz and Oppelt dugouts for 20 October 1980 to 6 January 1981.

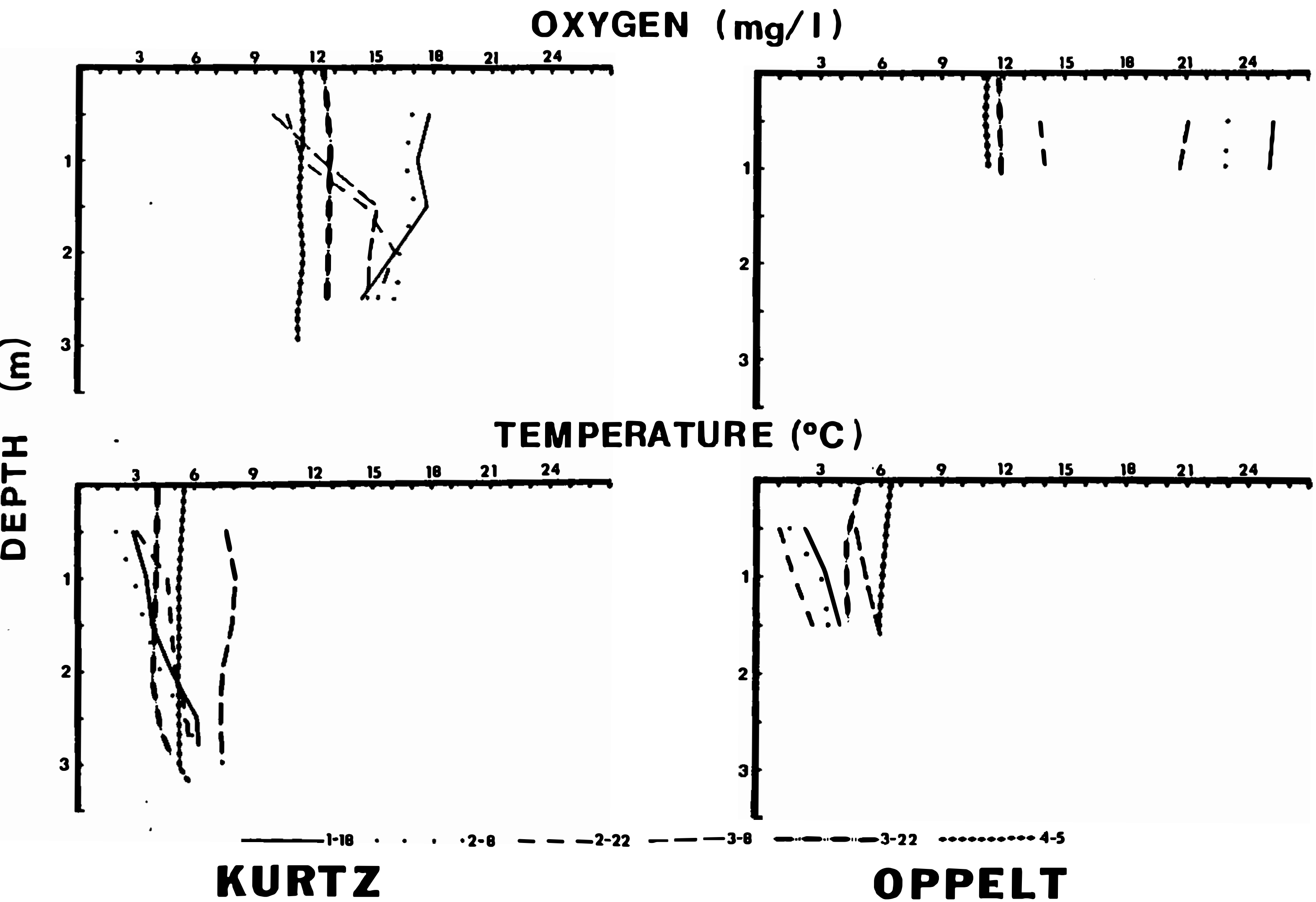

Figure 7. Mean dissolved oxygen and temperature profiles across stations by depth of Kurtz and Oppelt dugouts for 18 January 1981 to 5 April 1981.

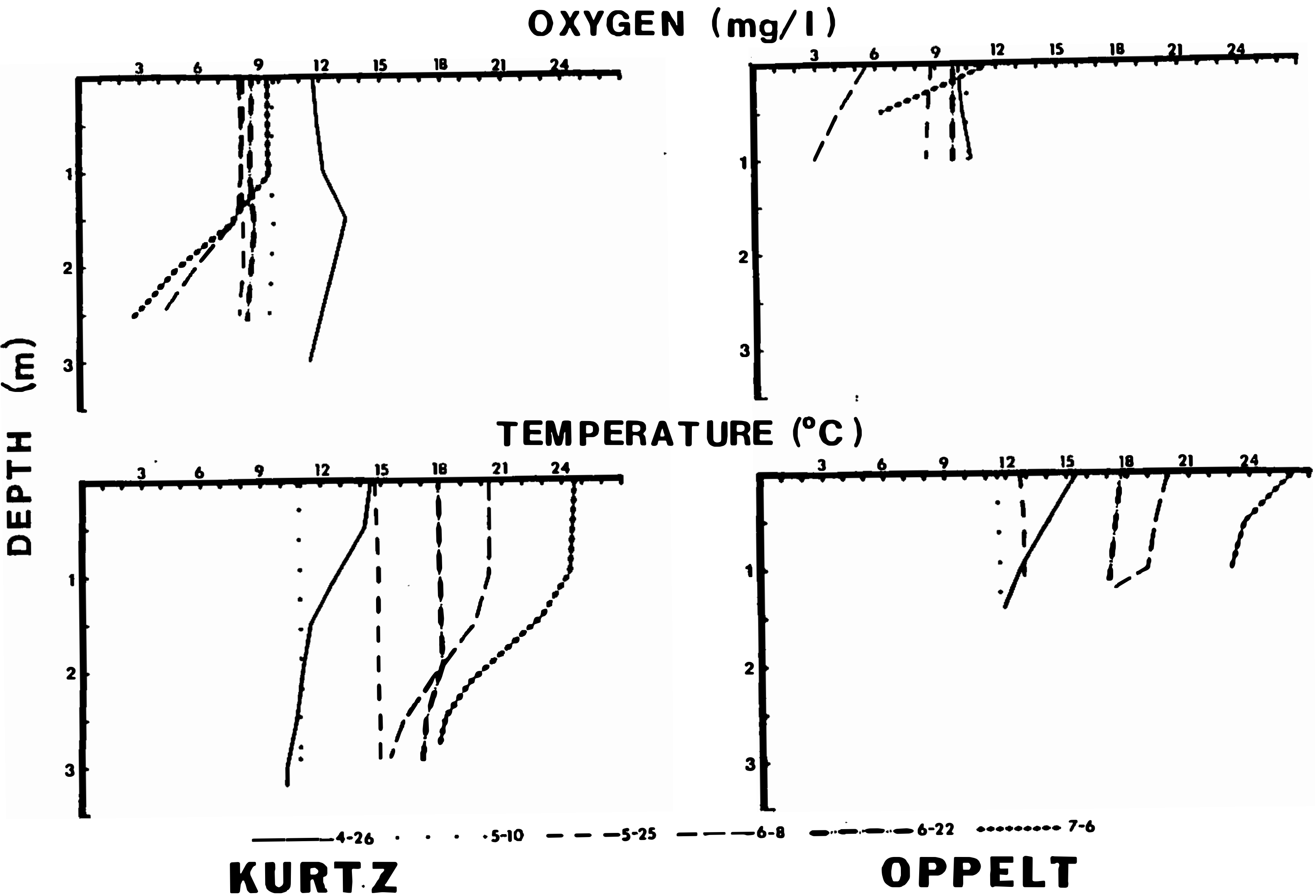

Figure 8. Mean dissolved oxygen and temperature profiles across stations by depth of Kurtz and Oppelt dugouts for 26 April 1981 to 6 July 1981.

1981 to 5 April 1981 (Fig. 7), surface oxygen decreased from 17.8-11.3 mg/l and temperature increased from 2.8-5.5 C in Kurtz. Surface oxygen decreased from 25.3-11.2 mg/l and temperature increased from 2.3-6.5 C in Oppelt. From 26 April 1981 to 6 July 1981 (Fig. 8), surface oxygen generally decreased from 11.7-9.4 mg/l and temperature increased from 14.5-24.6 C in Kurtz. Surface oxygen was consistent from 10.1-11.5 mg/l and temperature increased from 15.5-26.2 C in Oppelt.

In an idealized lake, the oxygen concentration prior to and after ice cover is at or near 100% saturation, which would be between 12-13 mg/l oxygen if occurring at about 4.0 C (Wetzel 1975; Boyd 1979). During this study, ice cover occurred from the end of November to the middle of March. A partial thaw occurred the 22 February 1981, which accounted for the drop in oxygen concentrations as the gas escaped to the atmosphere. Temperature tended to increase under the ice, due either to heating from the sediments or to the clarity of the ice allowing for light penetration. Temperature beneath the ice ranged from 1.9-7.6 C in Kurtz and from 1.0-4.8 C in Oppelt. Ice was snow covered from January to February 1981, which is reflected by the decline in oxygen and temperature during this period (Fig. 7). Maximum ice thickness during this study was 0.4 m with ice clarity ranging from clear to opaque.

The oxygen concentration began to exceed the saturation level in both dugouts from about 7 September 1980 to 22 March 1981. This increase is most probably due to wind mixing, water cooling, and the period of ice cover. The most striking difference between the 2 dugouts concerning oxygen concentration occurred during ice cover. Prior to ice formation, the oxygen concentration in Kurtz remained above the concentration in Oppelt. After ice formation, the oxygen concentration in Oppelt exceeded that of Kurtz (Fig. 6-7). From 14 December 1980 to 8 March 1981, Oppelt oxygen concentration exceeded 21.1 mg/l with a maximum level of 26.5 mg/l, but the Kurtz oxygen concentration never exceeded 17.8 mg/l during this period. The reversal in oxygen concentrations may indicate the differences in productivity between the 2 dugouts. The Oppelt pond was excavated in 1977 and probably has an established phytoplankton community as observed by the oxygen production under the ice, whereas the Kurtz pond was excavated in 1980 and probably was establishing a phytoplankton community.

Oxygen depth profiles were similar for both dugouts, except for the tendency of greater oxygen depletion near the sediments in Oppelt compared to Kurtz. The greatest surface to bottom difference in oxygen was 11.7 mg/l (13.0-1.3 mg/l) on 12 August 1980 in Oppelt; probably associated with an algal bloom and collapse. The greatest surface to bottom difference in oxygen was 6.7 mg/l (9.4-2.7 mg/l) on 6 July 1981 in Kurtz.

Oxygen profiles for Kurtz tended to be fairly uniform from surface to bottom in 1980 (Fig. 5-6), but greater fluctuations occurred from surface to bottom in 1981 (Fig. 7-8). Increased primary production through pond aging processes could be a possible explanation for this phenomenon. Oppelt had similar oxygen profiles in the summers of 1980 and 1981.

Maximum depth declined in both dugouts during the study period (Appendix 6). The greatest depth for Kurtz and Oppelt were 3.4 m and 2.5 m, respectively, occurring on 20 July 1980, and the lowest depth for Kurtz and Oppelt were 2.7 m and 0.9 m, respectively, occurring on 6 July, 1981.

Water clarity varied with sampling dates and observed turbidity increases were associated with livestock watering. Secchi disc visibility fluctuated from 35-165 cm in Kurtz (Table 12), and from 13-105 cm in Oppelt (Table 13). Both dugouts had lowered water visibility prior to and after ice cover, which could be associated with vertical mixing of the water column. Turbidity readings were less than 85 JTU on all sampling dates in the Kurtz dugout. Turbidity readings were generally less than 85 JTU in the Oppelt dugout except for readings of 110 JTU on 20 July 1980, 90 JTU on 20 October 1980, 155 JTU on 8 June 1981, and 270 JTU on 6 July 1981.

Specific conductance and salinity readings were consistently higher in the Kurtz pond compared to the Oppelt pond (Appendix 6). Surface conductivity readings ranged from 653-1037 µmhos in Kurtz, with the higher readings occurring under ice cover when ions were concentrated during ice formation (Barica 1977). Oppelt had a range in conductivity of 268-626 µmhos. Higher values were attained on 21 September and 6 October 1980, which were unexpected and may have been due to an alternate YSI Model 33 S-C-T meter used during these dates; the project meter was being repaired. Generally, the greater the concentration of ions in natural water, the larger the conductivity (Boyd 1979). The higher conductivity readings in Kurtz compared to Oppelt could be explained by the greater concentration of hardness causing ions (Table 12-13) in Kurtz.

Reid (1961) stated that evaporation from closed lakes can cause conductivity to increase over 10 fold. This phenomenon did not occur in the Oppelt dugout when depth declined to 0.92 m. Conductivity tended to increase with depth in both dugouts. The reason for this increase is

Table 12. Chemical-physical properties of Kurtz dugout, 1980-1981.

	1980										
Parameter Date:	7-20	8-12	8-24	9-7	9-21	10-6	10-20	11-3	11-23	12-2	12-14
Secchi Disc (cm)	58	125	165	115	110	65	70	75	75	80	100
Turbidity (JTU)	<85	<85	<85	<85	<85	<85	<85	<85	<85	<85	<85
pH	8.24	8.24	8.24	8.24	8.24	8.24	8.24	8.24	8.01	8.24	7.48
Free Carbon Dioxide (CO_2)	0	0	0	1.0	1.5	6.0	4.0	10.0	6.0	11.0	10.0
Total Alkalinity ($CaCO_3$)	160	183	166	150	166	164	162	188	198	214	204
Carbonate	12	14	20	0	0	0	0	0	0	0	0
Bicarbonate	148	169	146	150	166	164	162	188	198	214	204
Total Hardness ($CaCO_3$)	359	436	378	362	459	448	424	451	389	559	626
Carbonate Hardness ($CaCO_3$)	160	183	166	150	166	164	162	188	198	214	204
Noncarbonate Hardness ($CaCO_3$)	199	253	212	212	293	284	262	263	191	345	422
Calcium (Ca)	96	112	100	92	98	100	132	141	136	128	160
Magnesium (Mg)	29	38	31	32	52	48	23	24	12	58	55
Iron (Fe)	.18	.09	.08	.13	*	.4	.08	.04	.08	.12	.09
Manganese (Mn)	.05	.05	.1	0	*	0	0	0	0	0	0
Phosphate (P)											
Ortho-	.005	.01	.01	.005	.01	.01	.005	.015	.01	.02	.01
Total	.05	.03	.07	.03	.02	.04	.025	.03	.03	.04	.04
Nitrate (N)	.48	.25	.2	.1	.04	.11	.02	.08	.1	.08	.08
Ammonia (N)	.7	.7	.5	.3	.2	.1	.1	.3	.3	.3	.25
Chloride (Cl)	6	6	7	4	5	4	6	6	4	6	7
Potassium (K)	2	3	3	2	3	1	2	1	1	1	1
Sulfate (SO_4)	210	225	218	234	238	248	250	240	225	288	300
Sodium (Na)	6	5	5	5	6	5	5	5	7	7	6

Table 12. Continued.

Parameter	Date: 1-6	1-18	2-8	2-22	3-8	3-22	4-5	4-26	5-10	5-25	6-8	6-22	7-6
	1981												
Secchi Disc (cm)	100	90	130	135	90	99	40	60	35	75	75	50	60
Turbidity (JTU)	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85
pH	7.81	8.01	8.01	7.35	7.22	8.24	8.24	8.24	8.24	8.01	8.01	8.24	8.24
Free Carbon Dioxide (CO_2)	11.0	11.0	10.0	32.0	31.0	18.0	12.0	7.5	12.0	9.0	7.0	5.5	6.0
Total Alkalinity ($CaCO_3$)	281	298	305	287	263	277	257	204	217	199	193	198	197
Carbonate	0	0	0	0	0	0	0	0	0	0	0	0	0
Bicarbonate	281	298	305	287	263	277	257	204	217	199	193	198	197
Total Hardness ($CaCO_3$)	596	656	726	659	587	579	597	596	595	559	526	517	498
Carbonate Hardness ($CaCO_3$)	281	298	305	287	263	277	257	204	217	199	193	198	197
Noncarbonate Hardness ($CaCO_3$)	315	358	421	372	324	302	340	392	378	360	333	319	301
Calcium (Ca)	176	200	200	188	136	156	160	128	136	128	128	136	136
Magnesium (Mg)	38	38	55	46	60	46	48	67	62	58	50	43	38
Iron (Fe)	.1	.08	.14	.16	.1	.13	.08	.12	.25	.1	.04	.06	.22
Manganese (Mn)	.1	.05	0	.05	0	.1	.05	0	0	.1	.4	.05	.75
Phosphate (P)													
Ortho-	.02	.02	.02	.01	.01	.015	.01	.01	.02	.01	.005	.01	.01
Total	.04	.03	.025	.04	.025	.03	.04	.03	.05	.03	.025	.02	.04
Nitrate (N)	.05	.02	.08	.13	.15	.13	.28	.06	.03	.08	.01	.02	.04
Ammonia (N)	.2	.3	.1	.65	.2	.3	.2	.2	.3	.3	.2	.3	.4
Chloride (Cl)	7	9	12	8	11	8	10	9	10	10	7	6	6
Potassium (K)	2	2	2	2	1	2	2	1	1	1	2	1	2
Sulfate (SO_4)	384	356	400	320	302	305	303	305	385	350	340	340	383
Sodium (Na)	7	8	8	7	6	6	6	6	6	6	7	6	7

* No value determined.

Value expressed as mg/l of parameter in parenthesis.

Table 13. Chemical-physical properties of Oppelt dugout, 1980-1981.

	1980										
Parameter Date:	7-20	8-12	8-24	9-7	9-21	10-6	10-20	11-3	11-23	12-2	12-14
Secchi Disc (cm)	13	40	105	73	70	30	20	35	70	75	65
Turbidity (JTU)	110	<85	<85	<85	<85	<85	90	<85	<85	<85	<85
pH	7.48	8.82	9.17	8.51	8.51	8.24	8.01	8.24	8.24	7.48	7.48
Free Carbon Dioxide (CO_2)	1.5	0	0	0	0	4.0	3.5	10.0	6.5	1.0	10.0
Total Alkalinity ($CaCO_3$)	150	124	118	141	143	162	199	162	197	180	183
Carbonate	0	32	46	46	6	0	0	0	0	0	0
Bicarbonate	150	92	72	95	137	162	199	162	197	180	183
Total Hardness ($CaCO_3$)	174	219	179	154	208	210	206	330	228	300	258
Carbonate Hardness ($CaCO_3$)	150	124	118	141	143	162	199	162	197	180	183
Noncarbonate Hardness ($CaCO_3$)	24	95	61	13	61	48	7	168	31	120	75
Calcium (Ca)	49	40	32	38	42	40	74	71	60	72	80
Magnesium (Mg)	12	29	24	14	25	26	5	37	19	29	14
Iron (Fe)	.46	.08	.31	.58	*	1.35	.24	.05	.22	.25	.16
Manganese (Mn)	1.0	.05	0	.14	*	.2	0	0	0	0	0
Phosphate (P)											
Ortho-	.05	.01	.005	.005	.02	.01	.01	.01	.005	.02	.005
Total	.16	.1	.09	.05	.06	.08	.1	.09	.07	.08	.07
Nitrate (N)	.26	.1	.03	.08	.05	.08	.14	.14	.1	.1	.07
Ammonia (N)	2.0	1.0	.5	.75	.2	.5	.7	.9	.55	.5	.3
Chloride (Cl)	11	7	14	8	8	7	7	7	6	8	11
Potassium (K)	6	6	5	5	6	4	5	4	5	5	5
Sulfate (SO_4)	58	42	42	39	38	43	49	42	52	51	63
Sodium (Na)	3	3	3	3	4	4	4	4	4	6	5

Table 13. Continued.

Parameter Date:	1981												
	1-6	1-18	2-8	2-22	3-8	3-22	4-5	4-26	5-10	5-25	6-8	6-22	7-6
Secchi Disc (cm)	60	70	70	90	50	50	52	45	60	55	15	35	20
Turbidity (JTU)	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85	< 85	155	< 85	270
pH	8.51	8.51	8.51	8.24	8.82	8.24	8.01	8.24	8.24	8.24	8.01	8.51	8.51
Free Carbon Dioxide (CO_2)	0	0	0	9.0	0	6.0	11.0	7.0	3.0	8.0	8.0	0	0
Total Alkalinity ($CaCO_3$)	200	206	210	141	118	118	135	149	153	168	155	116	130
Carbonate	4	4	16	0	24	0	0	0	0	0	0	12	8
Bicarbonate	196	202	194	141	94	118	135	149	153	168	155	104	122
Total Hardness ($CaCO_3$)	319	336	360	221	169	165	320	260	250	250	270	198	176
Carbonate Hardness ($CaCO_3$)	200	206	210	141	118	118	135	149	153	168	155	116	130
Noncarbonate Hardness ($CaCO_3$)	119	130	150	80	51	47	185	111	97	82	115	82	46
Calcium (Ca)	80	72	88	52	43	46	52	48	80	60	48	56	43
Magnesium (Mg)	29	38	34	22	15	12	46	34	12	24	36	14	16
Iron (Fe)	.1	.14	.15	.16	.1	.17	.2	.21	.27	.54	.62	.25	.93
Manganese (Mn)	0	0	0	0	0	0	.1	0	.3	.25	.55	.1	.4
Phosphate (P)													
Ortho-	.01	.02	.01	.005	.01	.01	.01	.015	.015	.02	.025	.01	.01
Total	.08	.08	.08	.09	.08	.06	.08	.065	.09	.08	.07	.1	.13
Nitrate (N)	.1	.1	.06	.25	.03	.08	.11	.1	.04	.08	.11	.09	.08
Ammonia (N)	.5	.4	.15	.7	.6	.6	.5	.6	.4	.5	.8	.55	.2
Chloride (Cl)	16	16	18	14	15	14	13	17	16	13	13	16	14
Potassium (K)	7	9	9	7	5	5	5	5	6	6	7	5	10
Sulfate (SO_4)	92	98	126	66	60	52	62	61	66	70	75	75	78
Sodium (Na)	6	7	7	5	4	3	4	4	5	5	5	5	6

* No value determined.

Values expressed as mg/l of parameter in parenthesis.

uncertain, but could have resulted from calculated temperature correction to 25 C or from different settling rates for different ions in the water column.

Salinity rarely exceeded 0.2 ^{o}/oo in the Kurtz dugout and 0.0 ^{o}/oo in the Oppelt dugout. Salinity reached a high of 0.4 ^{o}/oo on 8 March 1981 in Kurtz when the ice was melting and mixing of the water occurred. Salinity is the total concentration of all ionic constituents present in water (Boyd 1979). The higher salinity readings in Kurtz compared to Oppelt could be explained by the greater concentration of hardness causing ions (Table 12-13) in Kurtz.

Little variation existed in the seasonal pattern of alkalinity between the 2 dugouts (Fig. 9-10). They generally increased from a summer minimum to winter maximum. Total alkalinity varied from 150-305 mg/l in Kurtz (Table 12) and from 118-210 mg/l in Oppelt (Table 13). Higher alkalinity values were attained during winter months because ions settle out during ice formation and associate with carbonates and bicarbonates in the water (Boyd 1979).

Alkalinity is usually divided into hydroxide, carbonate, and bicarbonate components. Hydroxide alkalinity did not occur in either dugout, but carbonate alkalinity did occur. Carbonate and bicarbonate alkalinities can be calculated stoichiometrically, that is, carbonate alkalinity equals 2 X phenolphthalein alkalinity, and bicarbonate alkalinity equals total alkalinity minus carbonate alkalinity (Sawyer and McCarty 1978). For the 2 dugouts studied, carbonate alkalinity prevailed when pH values exceeded 8.3, but bicarbonate alkalinity prevailed on all sampling dates.

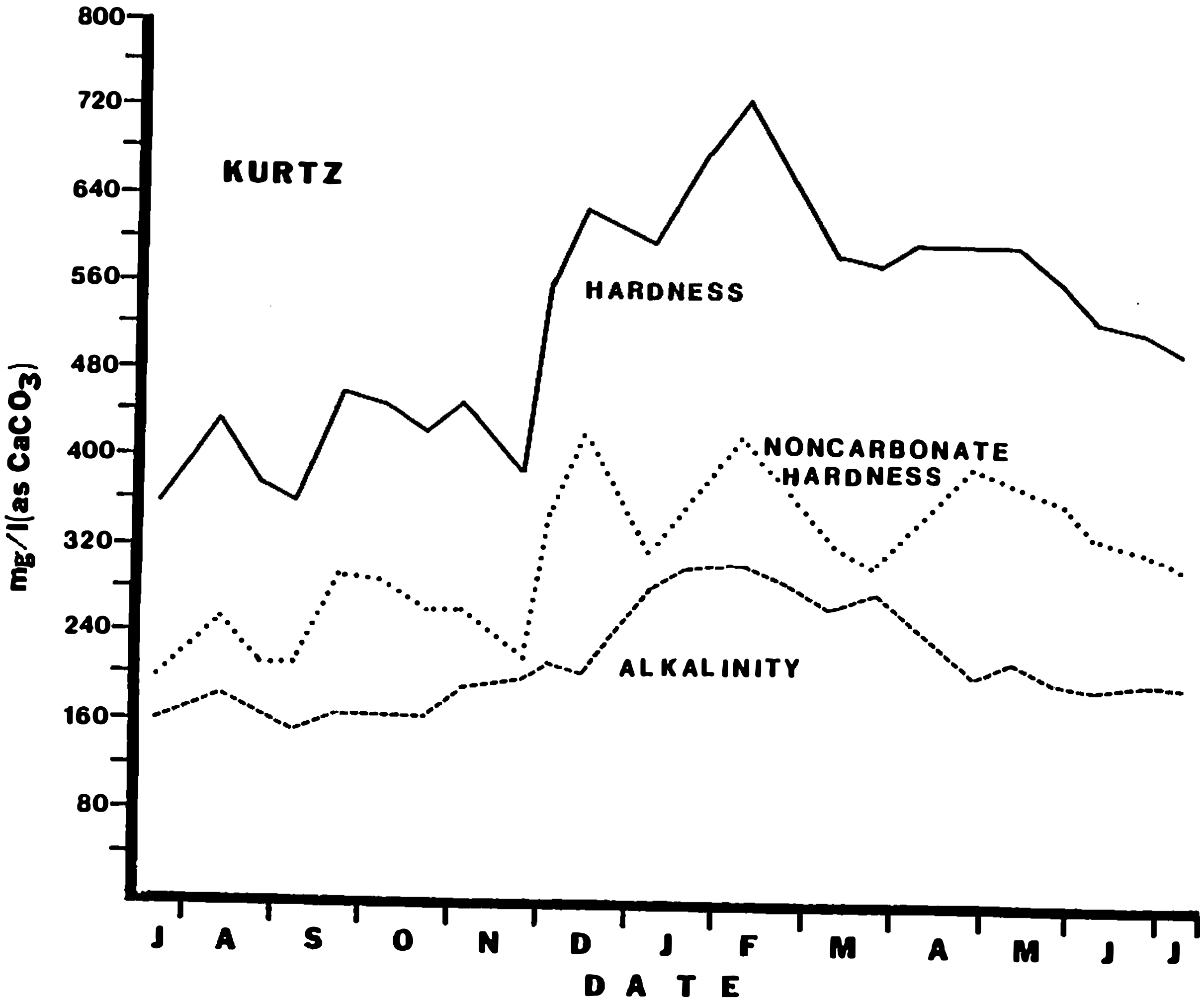

Figure 9. Seasonal cycle of total hardness, carbonate hardness (alkalinity), and noncarbonate hardness for Kurtz dugout, 1980-1981.

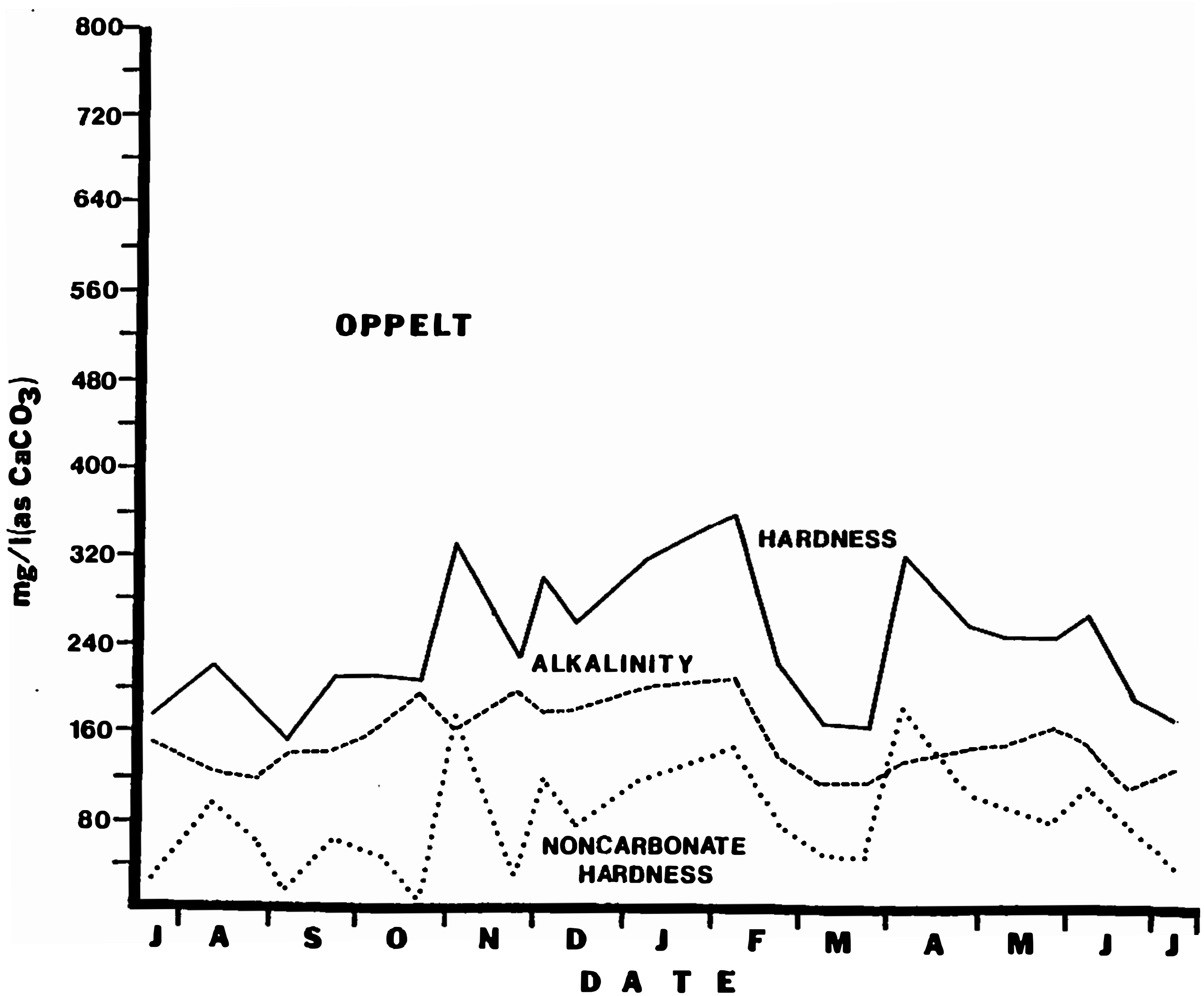

Figure 10. Seasonal cycle of total hardness, carbonate hardness (alkalinity), and noncarbonate hardness for Oppelt dugout, 1980-1981.

Free carbon dioxide occurred in both dugouts when pH values were below 8.3. Ranges in attained values were from 0-32 mg/l in Kurtz, and from 0-11 mg/l in Oppelt. The high Kurtz values occurred during ice cover when phytoplankton was actively respiring. An alternate method of carbon dioxide determination should have been chosen since titration end points were difficult to determine.

Ranges in pH values were from 7.22-8.24 in Kurtz and from 7.48-9.17 in Oppelt. The low Kurtz pH values corresponded with high carbon dioxide concentrations and ice cover. The pH values calculated were approximate figures due to the inaccuracy of the test kit used.

Little variation existed in the seasonal cycle of hardness between the 2 dugouts. Hardness generally increased from a summer minimum to winter maximum (Fig. 9-10). The Kurtz dugout was consistently greater in the 3 forms of hardness than the Oppelt dugout. Total hardness ranged from 359-726 mg/l in Kurtz, and from 165-360 mg/l in Oppelt. Carbonate hardness (Alkalinity) ranged from 150-305 mg/l in Kurtz, and from 116-210 mg/l in Oppelt. Noncarbonate hardness ranged from 191-422 mg/l in Kurtz, and from 7-185 mg/l in Oppelt (Table 12-13).

Hardness is caused by divalent metalic cations which are capable of reacting with soap to form precipitates (Sawyer and McCarty 1978). The principle hardness causing cations used for calculation of total hardness for this study were calcium, magnesium, iron, and manganous ions. The part of the total hardness that is chemically equivalent to the bicarbonate plus carbonate alkalinities (total alkalinity) present in the water is considered to be carbonate hardness. The amount of hardness which is in excess of the carbonate hardness is called noncarbonate hardness (total hardness - alkalinity). Noncarbonate hardness cations are associated with sulfate, chloride, and nitrate anions. All forms of hardness are expressed as calcium carbonate.

Noncarbonate hardness was always greater than the carbonate hardness in the Kurtz dugout (Fig. 9), but carbonate hardness was generally greater than noncarbonate hardness in the Oppelt dugout (Fig. 10). Since noncarbonate hardness is generally associated with the anions present in the water, the difference between the 2 dugouts is primarily due to sulfate concentrations. Sulfates were always greater than the carbonate hardness in the Kurtz pond (Table 12), but always less in the Oppelt pond (Table 13). Sulfates generally increased from a summer minimum to winter maximum, with ranges from 210-400 mg/l in Kurtz and from 38-126 mg/l in Oppelt.

The sudden decline in hardness from February to March 1981 coincided with the end of ice cover and increased dilution. The unusual increase in hardness on 5 April 1981 was associated with a sudden increase in magnesium on that date. Kurtz hardness did not fall to approximately the same level in July 1981 as in July 1980. Calcium was used to calculate total hardness and concentrations increased from 1980 to 1981 (Table 12).

Calcium, magnesium, iron, and manganese cations had similar seasonal patterns for the 2 dugouts (Table 12-13). Calcium ranged from 92-200 mg/l in Kurtz and from 32-88 mg/l in Oppelt. Magnesium ranged from 12-67 mg/l in Kurtz and from 5-46 mg/l in Oppelt. Calcium and magnesium had higher values during the winter months due to precipitation into the water during ice formation. Iron ranged from 0.04-0.25 mg/l in Kurtz and from 0.05-0,93 mg/l in Oppelt. Manganese ranged from 0.00-0.75 mg/l in Kurtz and from 0.00-1.00 in Oppelt. When oxygen falls to near zero at the sediment/water interface, a ferrous condition results where iron and mangenese go into solution in the water column (Wetzel 1975); accounting for the higher concentrations of iron and mangenese on certain dates during the study.

Nitrogen and phosphorous are essential to living organisms due to their roles in protein metabolism and energy transfer (Schmidt 1967). Ortho- and total phosphate, nitrate-N, and ammonia-N were determined and no consistent seasonal pattern was noticed (Table 12-13). Orthophosphate ranged from 0.005-0.020 mg/l in Kurtz and from 0.005-0.025 mg/l in Oppelt. Total phosphate ranged from 0.02-0.07 mg/l in Kurtz and from 0.05-0.15 in Oppelt. Nitrate-N ranged 0.01-0.48 mg/l in Kurtz and from 0.03-0.26 mg/l in Oppelt. Ammonia-N ranged from 0.1-0.7 mg/l in Kurtz and from 0.2-2.0 mg/l in Oppelt.

Potassium, sodium, and chloride displayed no seasonal pattern, but potassium and chloride concentrations tended to be greater in the Oppelt dugout; possibly due to soil fertility (Boyd 1979). Potassium ranged from 1-3 mg/l in Kurtz and from 4-10 mg/l in Oppelt. Sodium ranged from 5-8 mg/l in Kurtz and from 3-7 mg/l in Oppelt. Chlorides ranged from 4-12 mg/l in Kurtz and from 6-18 mg/l in Oppelt.

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APPENDIX

Appendix 1. Physical description of study dugouts and numbers of rainbow trout (*Salmo gairdneri*) and fathead minnows (*Pimephales promelas*) stocked, 1980.

Name	County	Legal Description Section	Township	Range	Hectares	Stocking Combination	# RbT Stocked[1]	# FhM Stocked[2]
Sutton	Brookings	SE¼	25	111-48	0.049	1977/ha FS	96	131
Bruemmer	Brookings	SW¼	11	109-48	0.061	1977/ha FS	121	160
Berg #1	Kingsbury	SE¼	35	110-53	0.033	1977/ha FS	65	95
Starkenburg	Brookings	NE¼	33	111-51	0.043	1483/ha FS	63	115
Sterud	Brookings	SE¼	33	109-50	0.049	1483/ha FS	73	125
Gullickson	Moody	SE¼	17	108-48	0.057	1483/ha FS	84	145
Apland	Brookings	SE¼	26	112-51	0.043	988/ha FS	43	111
Workman	Brookings	NW¼	17	112-49	0.078	988/ha FS	77	200
Berg #2	Kingsbury	NE¼	16	109-53	0.074	988/ha FS	73	195
Christensen	Brookings	NW¼	24	111-52	0.076	494/ha FS	37	192
Jensen	Brookings	NW¼	14	111-52	0.037	494/ha FS	18	103
Moore	Moody	NW¼	16	108-49	0.050	494/ha FS	25	127
Harvey	Brookings	NE¼	32	110-50	0.079	494/ha S	39	0
Kurtz	Brookings	NE¼SW¼	31	111-47	0.045	494/ha S	22	0
Matson	Moody	SW¼	16	108-47	0.061	494/ha S	30	0
Bain	Brookings	SW¼	6	112-49	0.064	494/ha	32	0
Hersrud #1	Moody	SE¼NE¼	22	108-50	0.084	494/ha	42	0
Hersrud #2	Moody	SW¼NE¼	22	108-50	0.096	494/ha	48	0
Olesen	Brookings	S½	31	109-52	0.110	Extra	272	0
Svennes	Brookings	S½	6	110-50	0.040	Extra	256	0
Nissen	Moody	SW¼SW¼	19	107-47	0.050	Extra	125	0

F - Fathead minnows stocked.
S - Supplemental feeding.
1 Trout stocked 30 April, 1980.
2 Minnows stocked 17 April, 1980 at 2471/ha.

Appendix 2. Physical description of Kurtz and Oppelt dugouts for physical-chemical analysis, 1980-1981.

	Kurtz		Oppelt	
Legal description (Section Township Range)	NW ¼ 6	110-47	NW ¼ 1	110-48
Year excavated	1980		1977	
Hectares	0.032		0.038	
Width (m)	15.0		14.2	
Length (m)	21.3		26.6	

Appendix 3. Rainbow trout (Salmo gairdneri) capture data during sampling dates of dugouts, 1980.

Date	Dugout	No.	$\bar{x}$ length	Length range	$\bar{x}$ weight	Weight range
5/21	Sutton	6	167.8	150 - 179	52.3	36 - 64
	Bruemmer	6	149.2	131 - 164	35.0	20 - 40
	Berg #1	6	178.8	165 - 194	61.7	50 - 75
	Starkenburg	6	150.5	143 - 162	34.3	22 - 48
	Sterud	6	179.3	162 - 208	74.7	56 - 114
	Gullickson[a]	6	148.5	132 - 171	27.0	14 - 48
	Apland	6	173.8	151 - 199	59.7	32 - 94
	Workman	6	184.7	166 - 209	81.7	20 - 124
	Berg #2	6	178.2	160 - 200	63.3	40 - 88
	Christensen	4	165.8	148 - 187	54.0	30 - 70
	Jensen	4	153.5	136 - 177	40.5	32 - 50
	Moore[a]	6	180.8	152 - 198	74.5	42 - 90
	Harvey[a]	0	---	---	---	---
	Kurtz	6	177.2	159 - 197	75.3	46 - 102
	Matson[a]	6	157.2	146 - 180	41.2	30 - 60
	Bain	4	180.3	169 - 190	73.0	66 - 80
	Hersrud #1	6	160.2	138 - 172	47.3	34 - 62
	Hersrud #2	6	168.2	138 - 183	47.2	30 - 60
6/6	Sutton	6	165.3	142 - 179	46.5	33 - 57
	Bruemmer	6	162.8	144 - 196	44.7	30 - 69
	Berg #1	6	185.0	177 - 191	72.0	57 - 88
	Starkenburg	6	159.7	148 - 185	39.2	29 - 63
	Sterud	6	184.7	164 - 203	74.7	55 - 98
	Gullickson	6	158.7	149 - 169	36.0	31 - 43
	Apland	6	184.5	156 - 214	66.2	36 - 112
	Workman	6	211.0	194 - 242	119.8	94 - 174
	Berg #2	4	175.3	154 - 198	58.0	39 - 84
	Christensen	1	188.0	188	63.0	63
	Jensen	6	177.8	162 - 185	58.2	47 - 68
	Moore[b]	-	---	---	---	---
	Harvey	0	---	---	---	---
	Kurtz	4	201.3	187 - 214	99.0	85 - 119
	Matson	6	183.5	167 - 198	67.2	54 - 86
	Bain	1	215.0	215	126.0	126
	Hersrud #1	6	183.2	151 - 198	70.8	37 - 95
	Hersrud #2	6	179.3	163 - 190	63.2	49 - 75

Appendix 3. Continued.

6/20	Sutton	6	165.2	135 - 178	50.7	33 - 59
	Bruemmer	6	173.3	160 - 191	49.7	37 - 68
	Bert #1	6	198.5	190 - 215	96.2	77 - 121
	Starkenburg	4	166.5	148 - 189	46.5	29 - 67
	Sterud	6	190.0	144 - 205	75.7	32 - 89
	Gullickson	6	158.5	146 - 179	37.2	27 - 52
	Apland	6	189.0	157 - 216	71.7	37 - 104
	Workman	6	222.7	205 - 239	140.0	110 - 166
	Berg #2	1	169.0	169	55.0	55
	Christensen	3	184.7	174 - 194	70.0	51 - 81
	Jensen	6	187.8	173 - 198	68.7	54 - 86
	Moore	6	211.0	187 - 228	106.3	74 - 134
	Harvey	0	---	---	---	---
	Kurtz[b]	-	---	---	---	---
	Matson	3	183.3	168 - 187	83.3	62 - 100
	Bain	4	220.0	212 - 230	147.0	136 - 170
	Hersrud #1	6	201.0	197 - 205	100.8	95 - 109
	Hersrud #2	6	189.7	184 - 200	68.0	61 - 76
7/7	Sutton	6	176.3	156 - 194	55.5	39 - 70
	Bruemmer[c]	-	---	---	---	---
	Berg #1	0	---	---	---	---
	Starkenburg	4	160.5	149 - 172	40.3	32 - 55
	Sterud[c]	-	---	---	---	---
	Gullickson[c]	-	---	---	---	---
	Apland	0	---	---	---	---
	Workman	6	230.3	218 - 238	158.5	137 - 173
	Berg #2	0	---	---	---	---
	Christensen	0	---	---	---	---
	Jensen	0	---	---	---	---
	Moore[c]	-	---	---	---	---
	Harvey	0	---	---	---	---
	Kurtz	0	---	---	---	---
	Matson	1	228.0	228	123.0	123
	Bain	1	221.0	221	143.0	143
	Hersrud #1	4	209.0	199 - 213	116.0	102 - 128
	Hersrud #2	6	180.0	167 - 189	74.0	60 - 84

[a]Contamination by other fishes.

[b]No sample taken due to area flooded.

[c]No sample taken due to temperature stress.

Appendix 4. Rainbow trout (*Salmo gairdneri*) harvest data from dugouts, October 10-11, 1980.

Dugout	No.	$\bar{x}$ length	Length range	$\bar{x}$ weight	Weight range
Sutton	19	197.3	162-235	87.3	55-142
Bruemmer	0	---	---	---	---
Berg #1[a]	0	---	---	---	---
Starkenburg	0	---	---	---	---
Sterud	0	---	---	---	---
Gullickson	1	195.0	195	71.0	71
Apland	0	---	---	---	---
Workman[a]	4	276.8	250-289	217.5	180-245
Berg #2	0	---	---	---	---
Christensen	0	---	---	---	---
Jensen[a]	0	---	---	---	---
Moore	0	---	---	---	---
Harvey	0	---	---	---	---
Kurtz	0	---	---	---	---
Matson	1	274.0	274	272	272
Bain	0	---	---	---	---
Hersrud #1	0	---	---	---	---
Hersrud #2	0	---	---	---	---
Svennes[b]	2	204.5	197-212	95.5	87-104
Olesen[b]	0	---	---	---	---
Nissen[b]	12	263.2	246-287	209.7	174-260

[a] Rotenoned dugouts.

[b] Extra dugouts.

Appendix 5. Hach chemical-physical properties of rainbow trout (*Salmo gairdneri*) dugouts, 1980.

Date			Sutton	Bruemmer	Berg #1	Starkenburg	Sterud	Gullickson	Apland	Workman	Berg #2	Christensen	Jensen	Moore	Harvey	Kurtz	Matson	Bain	Hersrud #1	Hersrud #2
5/12-15	Depth (m)		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Oxygen (mg/l)	S[a]	9.8	9.8	9.4	12.6	7.2	10.2	10.2	12.0	8.0	9.8	9.0	7.8	4.8	11.2	6.8	10.4	9.2	11.4
		M[b]	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		B[c]	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Temp. (^oC)	S	12.0	16.0	11.0	14.0	12.0	15.2	14.0	13.0	11.0	14.0	13.0	14.0	13.0	12.0	14.8	13.0	12.0	12.0
		M	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Salinity ($^o/oo$)	S	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		M	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Sp. Cond. (µmhos/cm)	S	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		M	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Alk. ($CaCO_3$)	CO_3	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	60	0	40
		HCO_3	370	160	160	110	190	210	230	290	100	180	210	220	370	250	220	150	120	100
	Hardness ($CaCO_3$)		840	150	240	250	240	380	250	620	320	450	510	280	460	920	210	190	160	130
	CO_2 (mg/l)		16	8	12	0	16	8	8	4	12	8	16	16	24	16	16	0	12	0
	pH		8.01	8.24	8.24	9.17	8.01	8.01	8.24	8.24	7.64	8.24	8.01	8.01	7.81	8.24	7.81	8.82	8.24	9.17

Appendix 5. Continued.

Date		Sutton	Bruemmer	Berg #1	Starkenburg	Sterud	Gullickson	Apland	Workman	Berg #2	Christensen	Jensen	Moore	Harvey	Kurtz	Matson	Bain	Hersrud #1	Hersrud #2
6/20-25	Depth (m)	3.1	2.1	2.3	3.4	2.0	3.5	3.4	2.8	2.8	2.8	1.9	2.2	2.2	---[d]	2.7	3.5	2.4	2.2
Oxygen (mg/l)	S[a]	7.2	7.8	8.2	10.4	8.6	5.4	7.2	10.2	8.8	7.2	8.0	11.6	5.2	---	7.6	7.6	10.2	7.8
	M[b]	7.8	6.8	6.4	5.6	7.8	4.4	4.8	8.8	5.4	7.8	8.2	13.8	1.4	---	5.6	6.6	9.4	6.2
	B[c]	6.2	5.2	1.6	0	3.8	0	2.6	7.6	3.8	6.2	7.4	2.4	0	---	2.2	0	2.8	4.8
Temp. (^{o}C)	S	21.2	25.3	28.0	26.0	24.8	21.0	20.3	20.5	26.0	23.0	21.2	27.5	28.3	---	21.2	20.9	27.4	24.0
	M	15.8	19.2	21.6	19.6	22.5	18.8	18.5	20.5	20.7	19.7	19.8	22.0	22.2	---	20.2	20.5	20.3	19.8
	B	15.9	18.1	19.0	15.0	17.2	14.2	16.5	20.5	18.4	19.0	18.7	16.2	17.6	---	14.9	15.0	19.5	18.9
Salinity ($^{o}/oo$)	S	0	0	0	0	0	0	0	.2	0	0	.1	0	.5	---	0	0	0	0
	M	0	0	0	0	0	0	0	.2	0	0	.1	0	.5	---	0	0	0	0
	B	0	0	0	0	0	0	0	.2	0	0	.1	0	.7	---	0	0	0	0
Sp. Cond. (μmhos/cm)	S	111	309	626	419	473	415	262	970	713	345	1025	336	1637	---	330	185	355	244
	M	90	301	637	440	480	474	257	970	730	340	1023	348	1637	---	330	186	362	243
	B	187	312	655	464	673	570	279	970	736	391	1019	708	1794	---	403	293	364	248
Alk. ($CaCO_3$)	CO_3	0	0	0	40	0	0	0	60	0	0	0	70	0	---	20	0	10	0
	HCO_3	50	150	200	70	190	110	110	80	130	130	200	70	270	---	110	100	140	125
Hardness ($CaCO_3$)		70	170	260	210	265	210	130	470	310	180	470	190	370	---	140	90	185	135
CO_2 (mg/l)		4	4	8	0	12	6	12	4	8	12	16	0	24	---	0	8	4	8
pH		7.35	8.24	8.01	9.17	8.01	8.24	7.64	8.51	8.24	7.61	8.01	8.51	7.81	---	8.51	8.01	8.24	7.81

Appendix 5. Continued.

Date		Sutton	Bruemmer	Berg #1	Starkenburg	Sterud	Gullickson	Apland	Workman	Berg #2	Christensen	Jensen	Moore	Harvey	Kurtz	Matson	Bain	Hersrud #1	Hersrud #2
7/7-10	Depth (m)	2.9	3.2	2.3	3.5	2.3	3.4	3.4	2.9	2.8	2.8	2.0	2.3	---	3.6	2.6	3.4	2.5	2.3
Oxygen (mg/l)	S[a]	7.8	---[e]	8.4	11.4	12.4	7.4	3.4	10.8	7.0	4.8	5.4	18.0	---	9.4	9.6	12.8	7.6	5.6
	M[b]	14.8	---	7.8	6.0	5.4	6.6	2.2	8.6	6.4	3.0	4.4	13.4	---	2.8	7.2	2.8	8.2	2.2
	B[c]	2.2	---	1.8	0	7.6	0	.8	6.4	1.2	1.8	2.8	6.4	---	.6	4.0	0	3.4	1.4
Temp. (^oC)	S	28.4	28.0	27.0	24.9	34.2	26.5	23.1	29.2	26.8	24.8	24.7	26.5	---	28.1	27.5	28.5	32.1	26.9
	M	18.0	24.9	23.5	20.2	24.8	20.8	22.9	25.0	23.0	24.1	24.7	22.7	---	19.9	24.1	21.8	24.7	24.9
	B	15.8	24.0	20.0	17.0	23.6	13.2	21.7	23.9	20.0	23.8	24.0	16.2	---	16.0	17.9	15.9	20.6	24.9
Salinity ($^o/oo$)	S	0	0	0	0	0	0	0	0	0	0	.1	0	---	0	0	0	0	0
	M	0	0	0	0	0	0	0	0	0	0	.1	0	---	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	.1	0	---	0	0	0	0	0
Sp. Cond. (μmhos/cm)	S	235	344	577	382	485	461	318	865	682	326	990	293	---	431	323	197	376	269
	M	244	337	612	409	480	523	317	890	717	327	960	388	---	452	339	239	380	272
	B	708	510	693	440	612	717	342	908	759	408	1061	732	---	480	633	395	447	276
Alk. ($CaCO_3$)	CO_3	40	0	0	60	40	60	0	60	0	0	0	80	---	40	80	80	20	0
	HCO_3	50	170	150	110	140	30	140	130	130	190	190	20	---	70	60	30	110	190
Hardness ($CaCO_3$)		140	180	270	190	240	210	140	440	340	170	500	160	---	240	150	100	190	120
CO_2 (mg/l)		0	8	4	0	0	0	8	0	8	8	16	0	---	0	0	0	0	0
pH		8.82	7.22	8.24	9.17	8.24	9.17	7.48	9.17	8.24	7.48	8.24	9.17	---	8.51	9.17	9.17	8.51	8.01

Appendix 5. Continued.

Date			Sutton	Bruemmer	Berg #1	Starkenburg	Sterud	Gullickson	Apland	Workman	Berg #2	Christensen	Jensen	Moore	Harvey	Kurtz	Matson	Bain	Hersrud #1	Hersrud #2
7/22-25	Depth (m)		2.8	3.0	2.1	4.1	1.9	3.1	3.2	2.5	2.8	2.8	1.9	2.1	2.2	3.4	2.3	2.9	2.3	2.0
	Oxygen (mg/l)	S[a]	9.4	---[e]	5.6	13.2	9.8	7.0	6.4	9.2	7.2	9.4	11.4	14.2	4.0	6.2	10.4	12.6	7.0	4.0
		M[b]	5.2	---	6.2	5.6	5.6	7.2	5.0	9.6	7.4	6.4	8.2	13.8	4.2	5.8	12.0	9.8	7.2	4.2
		B[c]	1.8	---	5.6	.6	2.4	0	3.8	8.2	7.2	4.8	6.0	0	4.0	5.8	10.4	8.2	6.0	3.2
	Temp. (^oC)	S	25.0	26.1	21.3	27.8	23.2	25.2	25.1	26.8	25.2	27.3	28.1	26.0	20.6	22.1	28.0	27.3	23.1	23.4
		M	15.3	22.9	19.1	20.3	22.0	22.9	21.3	21.9	22.2	20.2	22.1	22.1	20.6	20.9	23.3	21.0	22.9	22.5
		B	14.7	22.5	19.0	19.8	21.8	14.0	21.1	21.1	22.0	19.3	21.5	17.3	20.6	20.6	21.9	20.1	21.5	21.8
	Salinity ($^o/oo$)	S	0	0	0	0	0	0	0	0	0	0	.1	0	.1	0	0	0	0	0
		M	0	0	0	0	0	0	0	0	0	0	.1	0	.1	0	0	0	0	0
		B	0	0	0	0	0	0	0	0	0	0	.1	0	.1	0	0	0	0	0
	Sp. Cond. (μmhos/cm)	S	173	374	642	308	391	430	362	902	710	195	902	320	992	488	316	259	423	315
		M	196	371	706	334	431	437	366	888	728	199	952	340	992	610	331	271	419	311
		B	279	439	661	348	473	938	396	927	770	269	963	720	1112	632	365	299	445	364
	Alk. ($CaCO_3$)	CO_3	0	0	0	60	20	20	0	40	0	20	20	60	0	0	80	60	0	0
		HCO_3	100	200	150	100	140	90	180	180	130	80	140	100	270	130	80	100	190	160
	Hardness ($CaCO_3$)		120	220	270	160	220	240	190	460	360	110	460	160	320	260	170	140	210	150
	CO_2 (mg/l)		4	---[e]	8	0	0	0	4	0	8	0	0	0	16	6	0	0	12	8
	pH		8.24	7.64	8.01	8.82	8.24	8.24	7.81	8.24	8.01	8.24	8.24	9.17	8.24	7.64	9.17	8.51	8.01	7.35

Appendix 5. Continued.

Date			Sutton	Bruemmer	Berg #1	Starkenburg	Sterud	Gullickson	Apland	Workman	Berg #2	Christensen	Jensen	Moore	Harvey	Kurtz	Matson	Bain	Hersrud #1	Hersrud #2
8/14-17	Depth (m)		2.3	2.9	2.1	3.7	1.7	2.9	2.8	2.4	2.7	2.7	1.7	1.9	1.9	3.2	2.2	2.9	2.2	2.0
	Oxygen (mg/l)	S[a]	10.8	6.2	5.8	7.8	12.0	6.0	7.6	8.8	10.4	9.0	7.4	21.2	4.8	6.2	7.6	3.6	8.8	6.8
		M[b]	12.0	6.0	4.8	8.0	5.2	5.8	7.8	8.8	7.6	8.6	7.2	17.4	3.0	5.0	8.0	3.0	7.6	6.2
		B[c]	2.8	5.8	3.4	7.8	2.6	4.4	8.0	8.8	7.2	9.0	7.2	2.6	1.2	5.8	8.2	3.4	5.6	4.6
	Temp. (^oC)	S	24.6	21.6	22.2	20.2	24.9	21.7	17.6	23.1	22.1	19.5	19.0	24.0	22.3	22.3	21.5	17.8	24.2	26.2
		M	20.8	20.8	21.5	18.8	21.3	21.3	17.7	23.0	21.8	18.8	18.5	20.0	21.1	21.2	21.5	17.7	21.1	22.0
		B	16.0	20.5	21.0	18.2	21.0	15.0	17.8	21.2	21.6	18.1	18.3	12.9	20.6	20.3	19.9	17.7	20.8	21.1
	Salinity ($^o/oo$)	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sp. Cond. (μmhos/cm)	S	184	388	653	333	357	460	396	926	717	295	874	315	1102	546	309	357	419	291
		M	190	396	696	336	382	474	403	926	738	291	874	336	1090	556	311	361	533	291
		B	432	434	763	369	399	947	403	948	738	301	909	534	1166	561	420	412	549	335
	Alk. ($CaCO_3$)	CO_3	60	0	0	0	50	0	0	40	20	0	0	80	0	0	80	0	0	0
		HCO_3	40	200	160	130	120	140	185	80	110	150	160	60	310	170	70	210	190	160
	Hardness ($CaCO_3$)		110	210	330	180	190	260	210	500	350	180	460	175	360	320	170	180	220	130
	CO_2 (mg/l)		0	8	8	12	0	16	16	0	0	22	22	0	24	12	0	20	4	8
	pH		9.17	8.01	7.81	8.01	8.24	7.81	8.01	8.51	8.24	8.01	8.01	8.51	7.81	8.01	9.17	7.64	7.81	7.81

Appendix 5. Continued.

Date			Sutton	Bruemmer	Berg #1	Starkenburg	Sterud	Gullickson	Apland	Workman	Berg #2	Christensen	Jensen	Moore	Harvey	Kurtz	Matson	Bain	Hersrud #1	Hersrud #2
8/25-26	Depth (m)		2.6	3.0	2.1	3.7	1.7	2.9	2.9	2.5	2.7	2.6	1.7	1.9	1.9	3.1	2.2	2.8	2.2	2.0
	Oxygen (mg/l)	S[a]	6.6	6.4	5.6	5.2	16.4	6.6	5.8	4.8	5.2	4.4	5.2	7.2	10.2	6.2	12.0	4.6	6.2	7.2
		M[b]	5.8	6.0	4.8	5.0	1.2	6.0	4.8	4.6	5.0	4.0	4.6	5.2	2.8	6.0	10.2	4.4	6.2	6.4
		B[c]	4.0	6.2	4.2	2.6	2.4	0	5.8	4.6	5.0	3.6	4.0	2.2	1.6	6.2	3.2	4.2	6.0	6.0
	Temp. (^oC)	S	18.8	19.1	19.2	19.1	25.9	21.4	19.0	19.3	18.8	19.4	19.1	21.1	26.4	19.5	28.0	18.9	21.8	21.0
		M	19.0	19.1	19.2	18.9	19.2	22.0	19.3	19.8	19.0	19.1	19.2	20.8	23.2	19.7	22.1	19.2	22.0	21.1
		B	15.8	19.7	19.2	18.0	17.9	15.8	19.2	19.8	18.9	15.9	19.0	17.8	20.3	19.5	19.0	19.1	21.5	20.1
	Salinity ($^o/oo$)	S	0	0	0	.2	0	0	0	0	0	0	0	0	.1	0	0	0	0	0
		M	0	0	0	.2	0	0	0	0	0	0	0	0	.1	0	0	0	0	0
		B	0	0	0	.2	0	0	0	0	0	0	0	0	.1	0	0	0	0	0
	Sp. Cond. (µmhos/cm)	S	216	372	661	360	335	487	422	930	717	361	818	259	1119	539	303	383	399	286
		M	220	372	672	361	389	482	427	913	739	364	829	293	1113	539	307	389	399	292
		B	400	388	672	380	451	732	431	913	784	391	874	543	1177	550	417	413	419	330
	Alk. ($CaCO_3$)	CO_3	20	0	0	20	80	0	0	0	0	0	0	60	0	0	100	0	0	0
		HCO_3	80	180	150	130	70	140	200	160	110	160	160	50	320	170	40	220	190	150
	Hardness ($CaCO_3$)		140	210	290	180	180	260	220	510	310	220	440	140	380	320	160	190	210	140
	CO_2 (mg/l)		0	8	4	0	0	8	8	10	4	4	8	0	8	4	0	8	10	6
	pH		8.24	7.81	8.24	8.24	9.17	7.81	7.81	7.81	8.01	7.64	8.24	9.17	8.01	8.01	9.17	7.81	8.01	8.01

Appendix 5. Continued.

Date			Sutton	Bruemmer	Berg #1	Starkenburg	Sterud	Gullickson	Apland	Workman	Berg #2	Christensen	Jensen	Moore	Harvey	Kurtz	Matson	Bain	Hersrud #1	Hersrud #2
9/12-13	Depth (m)		2.2	2.8	1.9	3.3	1.5	2.8	2.7	2.4	2.5	2.4	1.6	1.8	1.7	3.0	2.0	2.7	2.0	1.8
	Oxygen (mg/l)	S[a]	6.4	5.8	8.8	9.0	14.2	9.5	6.2	2.0	7.4	6.2	8.4	21.2	4.6	7.2	13.0	5.2	6.6	7.8
		M[b]	6.0	5.8	7.2	8.0	4.2	5.8	5.8	1.6	7.2	5.8	7.2	17.8	4.2	6.8	9.8	4.8	6.6	7.4
		B[c]	1.0	5.2	3.8	5.8	4.2	0	5.8	1.6	7.0	5.8	5.6	4.4	3.2	5.8	0	4.2	6.4	7.2
	Temp. (^oC)	S	18.4	18.1	18.9	18.5	20.8	22.0	18.0	18.0	18.9	18.1	18.7	22.0	19.6	18.6	22.0	17.9	20.5	20.8
		M	18.6	18.1	18.7	18.2	18.6	20.1	18.0	18.1	18.9	18.3	18.4	18.8	19.0	18.7	19.0	17.9	20.0	19.2
		B	17.4	18.1	17.9	18.0	18.4	17.4	18.0	18.1	18.9	18.4	18.2	17.9	18.3	18.2	18.2	17.9	19.2	18.8
	Salinity ($^o/oo$)	S	0	0	0	0	0	0	.5	.7	.1	.8	0	0	.5	0	.1	0	0	0
		M	0	0	0	0	0	0	.5	.7	.1	.8	0	0	.5	0	.1	0	0	0
		B	0	0	0	0	0	0	.5	.7	.1	.8	0	0	.5	0	.2	.1	0	0
	Sp. Cond. (μmhos/cm)	S	690	736	795	410	352	578	1587	1921	948	1898	1030	340	1485	627	909	932	687	353
		M	672	759	784	427	395	583	1507	1921	896	1874	1058	432	1456	728	907	932	660	358
		B	838	840	805	437	437	909	1587	1921	907	1944	1116	443	1518	840	1035	1024	706	426
	Alk. ($CaCO_3$)	CO_3	0	0	0	20	60	0	0	0	0	0	0	120	0	0	110	0	0	0
		HCO_3	115	210	145	80	80	160	200	215	135	170	170	0	330	180	55	205	200	160
	Hardness ($CaCO_3$)		130	200	310	170	180	260	230	540	380	220	470	160	400	300	150	180	220	145
	CO_2 (mg/l)		6	8	8	0	0	4	12	12	10	10	10	0	20	6	0	6	10	8
	pH		8.24	8.24	8.24	8.51	9.17	8.24	8.01	7.81	8.24	8.01	8.24	9.17	8.01	8.24	9.17	8.24	8.01	8.24

Appendix 5. Continued.

Date			Sutton	Bruemmer	Berg #1	Starkenburg	Sterud	Gullickson	Apland	Workman	Berg #2	Christensen	Jensen	Moore	Harvey	Kurtz	Matson	Bain	Hersrud #1	Hersrud #2
10/3-4	Depth (m)		2.0	2.7	1.8	3.0	1.2	2.6	2.5	2.2	2.4	2.2	1.4	1.6	1.5	2.9	1.9	2.6	1.8	1.6
	Oxygen (mg/l)	S[a]	7.4	8.8	8.2	15.6	8.0	9.2	10.2	6.6	8.6	8.6	10.6	8.6	7.2	8.8	8.8	8.2	10.0	9.8
		M[b]	7.0	8.6	8.0	9.6	7.5	8.4	10.2	6.2	8.2	8.4	9.8	8.2	7.0	8.6	7.8	7.6	8.8	9.6
		B[c]	6.8	8.6	7.6	7.8	7.0	7.6	9.2	6.0	7.8	8.0	7.4	7.2	6.6	8.2	7.4	6.8	8.2	8.8
	Temp. (°C)	S	8.0	9.1	9.2	16.1	9.2	12.0	11.1	8.1	9.2	14.5	14.8	11.4	8.8	8.1	10.2	10.1	10.4	11.1
		M	8.2	9.1	9.2	10.3	9.0	11.2	9.7	8.9	9.6	9.7	10.0	10.9	8.8	8.3	10.0	9.1	10.1	10.2
		B	8.7	9.0	9.3	10.0	9.1	11.0	9.1	8.8	9.6	9.1	9.9	10.7	8.9	8.5	9.9	8.9	9.8	9.8
	Salinity (o/oo)	S	0	0	.5	.1	0	0	.1	.2	.1	0	.6	0	.5	.3	0	0	0	0
		M	0	0	.5	.1	0	0	.1	.2	.1	0	.6	0	.5	.3	0	0	0	0
		B	0	0	.5	.1	0	0	.1	.2	.1	0	.6	0	.5	.3	0	0	0	0
	Sp. Cond. (μmhos/cm)	S	696	846	1593	1056	439	607	952	1291	1001	566	1587	336	1481	1320	395	469	513	390
		M	711	846	1551	1214	457	626	952	1255	980	566	1615	336	1466	1305	395	479	513	395
		B	733	860	1551	1242	603	694	987	1241	966	649	1711	392	1466	1297	400	496	551	425
	Alk. ($CaCO_3$)	CO_3	0	0	0	60	0	0	0	0	0	0	0	60	0	0	40	0	0	0
		HCO_3	150	190	155	100	190	180	220	230	140	210	180	80	330	180	110	220	220	200
	Hardness ($CaCO_3$)		160	210	350	190	220	290	240	610	340	270	520	170	440	360	170	200	240	180
	CO_2 (mg/l)		12	16	10	0	12	16	16	16	20	12	14	0	6	14	0	18	10	12
	pH		8.01	8.01	7.81	8.51	8.24	8.01	8.24	8.01	8.24	8.24	8.24	8.51	7.81	8.01	8.51	8.24	8.24	8.01

[a] Surface.
[b] Midwater.
[c] Bottom.
[d] Area flooded.
[e] Turbidity interference.

Appendix 6. Oxygen, temperature, salinity, and specific conductance profiles of Kurtz and Oppelt dugouts, July 1980 to July 1981.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (°/oo)	Sp. Cond. (μmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
7/20/80		S[a]	7.4	7.1	7.3	22.1	22.1	22.1	0	653	653	653
		0.5	6.9	6.8	7.1	22.3	22.3	22.1	0	653	653	653
		1.0	7.3	6.8		22.3	22.3		0	653	653	
	Kurtz	1.5	7.1	6.9		22.3	22.3		0	653	653	
		2.0	7.1			22.3	22.1(1.7)[b]		0	653	653(1.7)	
		2.5	6.8			22.1			0	663		
		3.0	6.3			22.0			0	717		
		3.5				21.1(3.4)			0(3.4)	807(3.4)		
		S	4.0	4.2	4.2	22.2	22.1	22.2	0	346	345	348
		0.5	3.5	4.0	4.0	22.0	22.1	22.2	0	341	347	353
	Oppelt	1.0	3.8	3.8		22.0	22.0		0	345	346	
		1.5	3.3			21.8	21.9(1.2)		0	342	396(1.2)	
		2.0	3.0			21.8			0	342		
		2.5				21.5(2.5)			0(2.5)	371(2.5)		

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (°/oo)	Sp. Cond. (μmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
8/12/80		S[a]	8.4	8.4	8.5	22.0	21.9	21.9	0	663	674	685
		0.5	8.4	8.5	8.6	21.9	21.9	21.9	0	663	674	685
		1.0	8.3	8.5		21.9	21.9		0	663	674	
	Kurtz	1.5	8.4	8.3		21.8	21.8(1.5)[b]		0	674	706(1.5)	
		2.0	8.3			21.8			0	674		
		2.5	8.3			21.8			0	674		
		3.0	8.1			21.7			0	717		
		3.5				21.5(3.1)			0(3.1)	717(3.1)		
		S	12.5	13.8	12.7	24.0	22.8	23.1	0	299	300	306
		0.5	12.1	13.7	13.3	21.9	21.5	22.8	0	302	302	304
	Oppelt	1.0	10.1	8.2		21.2	21.2		0	314	317	
		1.5	6.8			20.6	20.9(1.1)		0	335	339(1.1)	
		2.0	1.2			19.4			0	384		
		2.5				18.9(2.3)			0(2.3)	454(2.3)		
8/24/80		S	8.0	8.2	8.1	21.5	21.3	21.3	0	653	654	655
		0.5	7.9	7.9	8.0	21.3	21.3	21.2	0	665	654	654
		1.0	8.0	8.1		21.2	21.2		0	654	654	
	Kurtz	1.5	8.1	7.9		21.2	21.2		0	654	654	
		2.0	7.9			21.1	21.1(1.6)		0	654	654(1.6)	
		2.5	7.9			21.1			0	654		
		3.0	7.9			21.1			0	654		
		3.5				21.0(3.2)			0(3.2)	665(3.2)		
		S	8.3	8.5	8.5	23.7	23.5	23.5	0	266	267	271
		0.5	8.2	8.5	8.7	22.9	23.0	23.0	0	268	267	274
	Oppelt	1.0	8.9	8.1		21.9	22.0		0	273	276	
		1.5	8.5			20.9	21.0(1.1)		0	286	300(1.1)	
		2.0	5.0			19.1			0	311		
		2.5				18.6(2.3)			0(2.3)	366(2.3)		

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (o/oo)	Sp. Cond. (µmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
9/7/80		S[a]	9.0	9.0	9.6	22.3	22.2	22.2	0	663	674	674
		0.5	9.4	9.2	9.3	22.3	22.2	22.2	0	663	674	674
		1.0	9.2	10.2		22.0	21.5		0	642	653	
	Kurtz	1.5	9.7	9.8		21.7	20.9		0	631	654	
		2.0	9.4			20.2	20.9(1.6)[b]		0	643	643(1.6)	
		2.5	9.0			20.0			0	660		
		3.0	8.1			19.0			0(3.2)	694		
		3.5				18.9(3.2)				762(3.2)		
		S	9.3	9.1	9.1	25.0	25.0	25.0	0	293	298	296
		0.5	9.7	9.9	9.6	23.1	22.9	23.1	0	295	296	307
	Oppelt	1.0	9.5	9.2		21.0	20.7		0	295	295	
		1.5	8.4			19.6	20.1(1.1)		0	300	318(1.1)	
		2.0	5.4			19.0			0	318		
		2.5				18.9(2.2)			0(2.2)	372(2.2)		
9/21/80		S	9.7	9.6	9.4	14.0	14.0	14.0	0	888	888	888
		0.5	9.3	9.5	9.6	14.1	14.1	14.0	0	888	888	888
		1.0	9.4	9.5		14.1	14.1		0	888	888	
	Kurtz	1.5	9.6	9.4		14.1	14.1		0	888	888	
		2.0	9.4			14.0	14.2(1.6)		0	888	900(1.6)	
		2.5	9.3			14.0			0	888		
		3.0	9.2			14.0			0	900		
		3.5				14.2(3.1)			0(3.1)	900(3.1)		
		S	8.4	8.3	8.4	15.3	14.9	15.1	0	1144	1119	1107
		0.5	8.1	8.3	8.3	14.9	14.8	15.0	0	1144	1107	1107
	Oppelt	1.0	8.2	7.9		14.0	14.4(1.0)		0	1163	1150(1.0)	
		1.5	8.0			13.8			0	1163		
		2.0	7.6			13.8(2.1)			0(2.1)	1200(2.1)		
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (o/oo)	Sp. Cond. (μmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
10/6/80		S[a]	10.2	10.4	10.3	16.1	15.1	15.2	0	792	775	787
		0.5	10.4	10.4	10.6	13.5	13.2	13.6	0	763	781	788
		1.0	10.3	10.6		12.0	12.1		0	779	792	
	Kurtz	1.5	10.6	10.6		11.0	10.9		0	802	802	
		2.0	10.5			10.8	10.5(1.6)[b]		0	802	816(1.6)	
		2.5	10.3			10.5			0	802		
		3.0				10.4(2.9)			0(2.9)	828(2.9)		
		3.5										
		S	9.8	9.6	9.6	14.0	15.1	15.2	0	738	443	406
		0.5	9.8	9.8	9.9	11.0	11.6	11.7	0	544	409	409
	Oppelt	1.0	9.5	8.7		9.5	9.2(.9)		0	442	423(.9)	
		1.5	8.5			9.0			0	423		
		2.0				9.1(1.9)			0(1.9)	494(1.9)		
		2.5										
10/20/80		S	11.3	11.6	12.0	8.1	7.8	7.8	.2	711	711	711
		0.5	11.4	11.6	11.7	6.8	7.0	7.2	.2	720	735	735
		1.0	11.5	11.6		6.8	6.6		.2	720	720	
	Kurtz	1.5	11.7	11.6		6.0	6.0(1.5)		.2	739	739(1.5)	
		2.0	11.7			5.9			.2	739		
		2.5	12.5			5.9			.2	739		
		3.0				6.9(3.0)			.2(3.0)	810(3.0)		
		3.5										
		S	10.8	10.8	10.7	8.6	7.9	8.0	0	340	352	360
		0.5	10.8	10.8	10.8	8.0	7.8	7.9	0	349	352	355
	Oppelt	1.0	10.6			7.2	7.5(.9)		0	357	358(.9)	
		1.5	10.2			6.1			0	367		
		2.0				6.0(1.8)			0(1.8)	380(1.8)		
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (^oC)			Salinity ($^o/oo$)	Sp. Cond. (μmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
11/3/80		S[a]	12.3	12.3	12.3	7.0	6.9	6.9	0	735	735	735
		0.5	12.3	12.3	12.5	6.6	6.6	6.6	0	735	735	735
		1.0	12.4	12.4		6.4	6.5		0	755	735	
	Kurtz	1.5	12.5	12.3		6.3	6.4		0	755	755	
		2.0	12.5			6.1	6.2(1.6)[b]		0	755	739(1.6)	
		2.5	12.3			6.0			0	755		
		3.0				6.1(2.9)			0(2.9)	739(2.9)		
		3.5										
		S	11.0	11.1	10.9	7.5	7.3	7.4	0	711	585	585
		0.5	11.0	11.0	11.1	7.2	7.2	7.2	0	735	585	585
	Oppelt	1.0	11.1	10.9		7.1	7.1(.9)		0	720	540(.9)	
		1.5	11.0			7.0			0	585		
		2.0				7.1(1.8)			0(1.8)	525(1.8)		
		2.5										
11/23/80		S	13.0	ICE		1.9	ICE		.2	833	ICE	
		0.5	12.9	13.1	---	2.1	2.0	---	.2	833	833	---
		1.0	13.0	13.1		2.5	2.4		.2	813	833	
	Kurtz	1.5	13.2			2.8	2.8		.2	813	813	
		2.0	13.1			2.9	3.0(1.6)		.2	813	830(1.6)	
		2.5	13.1			3.0			.2	830		
		3.0				5.0(3.0)			.3(3.0)	1178(3.0)		
		3.5										
		S	12.8	ICE		2.2	ICE		.1	357	ICE	
		0.5	12.8	12.9	---	2.5	2.5	---	.1	357	357	---
	Oppelt	1.0	12.6	12.9		2.7	2.7		.1	365	365	
		1.5	12.6			3.1	2.8		.1	365	365(1.4)	
		2.0				3.2(1.7)			.1(1.7)	365(1.7)		
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l) 1	2	3	Temperature (°C) 1	2	3	Salinity (o/oo) 1	Sp. Cond. (µmhos/cm) 1	2	3
12/2/80		S[a]		ICE			ICE		ICE		ICE	
		0.5	15.7	c	---	3.0	2.9	---	.2	813	813	---
		1.0	15.4	15.5		3.1	3.2		.2	813	813	
	Kurtz	1.5	16.0			3.1	3.5(1.5)[b]		.2	830	810(1.5)	
		2.0	15.6			3.4			.2	830		
		2.5	c			5.0			.2	895		
		3.0				6.0(3.0)			.5(3.0)	1247(3.0)		
		3.5										
		S		ICE			ICE		ICE		ICE	
		0.5	15.0	15.2	---	1.2	2.0	---	0	353	362	---
	Oppelt	1.0	15.0	15.2		2.1	2.5(.8)		0	362	354(.8)	
		1.5	c			3.4			0	383		
		2.0				3.4(1.6)			0(1.6)	383(1.6)		
		2.5										
12/14/80		S		ICE			ICE		ICE		ICE	
		0.5	16.9	17.0	---	3.4	3.2	---	.2	863	847	---
		1.0	16.8	16.9		3.6	3.3		.2	842	863	
	Kurtz	1.5	16.9	16.8		3.9	3.7		.2	842	842	
		2.0	16.0			4.7	3.9(1.6)		.2	895	859(1.6)	
		2.5	15.7			5.9			.3	1109		
		3.0				6.8(3.0)			.5(3.0)	1230(3.0)		
		3.5										
		S		ICE			ICE		ICE		ICE	
		0.5	21.3	21.9	---	3.2	3.3	---	0	398	408	---
	Oppelt	1.0	21.5			3.5	3.9(.9)		0	402	407(.9)	
		1.5				4.9(1.6)			0(1.6)	436(1.6)		
		2.0										
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (o/oo)	Sp. Cond. (µmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
1/6/81		S[a]		ICE			ICE		ICE		ICE	
		0.5	17.2	18.1	---	3.8	3.7	---	.1	907	940	---
		1.0	17.6	18.0		4.0	3.9		.1	923	972	
	Kurtz	1.5	17.9			4.1	4.0(1.5)[b]		.1	940	988(1.5)	
		2.0	17.8			4.7			.1	958		
		2.5	17.1			6.6			.2	1170		
		3.0				7.0(2.9)			.2(2.9)	1230(2.9)		
		3.5										
		S		ICE			ICE		ICE		ICE	
		0.5	26.1	26.9	---	3.3	2.6	---	0	428	430	---
	Oppelt	1.0	26.4			3.5	3.8(.7)		0	426	431(.7)	
		1.5				4.0(1.5)			0(1.5)	434(1.5)		
		2.0										
		2.5										
1/18/81		S		ICE			ICE		ICE		ICE	
		0.5	17.7	17.9	---	3.1	2.5	---	.2	996	1013	---
		1.0	17.6	16.9		3.8	3.1		.2	988	1013	
	Kurtz	1.5	17.7			4.4	3.2(1.4)		.2	1020	1013	
		2.0	16.1			4.8			.2	1021		
		2.5	14.4			6.1			.2	1217		
		3.0				6.2(2.8)			.2(2.8)	1247(2.8)		
		3.5										
		S		ICE			ICE		ICE		ICE	
		0.5	25.3	25.4	---	2.6	2.0	---	0	466	476	---
	Oppelt	1.0	25.1			3.3	3.5(.7)		0	483	475(.7)	
		1.5				4.0(1.5)			0(1.5)	504(1.5)		
		2.0										
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (o/oo)	Sp. Cond. (µmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
2/8/81		S[a]		ICE			ICE		ICE		ICE	
		0.5	16.6	17.1	---	1.9	1.8	---	.2	1037	1037	---
		1.0	16.9	16.3		2.7	2.8		.2	1029	1096	
	Kurtz	1.5	17.1			3.7	3.1(1.4)[b]		.2	1069	1129(1.4)	
		2.0	16.3			4.2			.2	1102		
		2.5	16.2			5.5			.2	1217		
		3.0				5.9(2.8)			.3(2.8)	1232(2.8)		
		3.5										
		S		ICE			ICE		ICE		ICE	
		0.5	22.6	23.4	---	2.1	1.0	---	0	507	520	---
	Oppelt	1.0	22.9			3.1	3.1(.7)		0	525	525(.7)	
		1.5				3.5(1.5)			0(1.5)	517(1.5)		
		2.0										
		2.5										
2/22/81		S		ICE			ICE		ICE		ICE	
		0.5	10.6	10.5	---	3.7	2.3	---	.2	891	867	---
		1.0	12.5	10.3		4.8	4.3		.2	1115	1102	
	Kurtz	1.5	14.6			4.9	4.7(1.4)		.3	1146	1130(1.4)	
		2.0	16.1			5.0			.3	1146		
		2.5	15.2			5.6			.3	1232		
		3.0				5.7(2.8)			.3(2.8)	1247(2.8)		
		3.5										
		S		ICE			ICE		ICE		ICE	
		0.5	13.8	13.9	---	1.2	.7	---	0	353	365	---
	Oppelt	1.0	14.1	14.2		2.1	1.5		0	394	393	
		1.5	14.4			3.1	2.3(1.1)		0	413	413(1.1)	
		2.0				3.3(1.6)			0(1.6)	442(1.6)		
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (‰)	Sp. Cond. (µmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
3/8/81		S[a]		ICE			ICE		ICE		ICE	
		0.5	10.8	9.0	---	7.9	7.2	---	.2	885	900	---
		1.0	12.9	11.8		8.2	7.9		.2	1160	1131	
	Kurtz	1.5	15.2			7.9	7.8(1.5)[b]		.2	1160	1160(1.5)	
		2.0	14.8			7.4			.4	1230		
		2.5	14.7			7.3			.4	1275		
		3.0				7.4(3.0)			.4(3.0)	1305(3.0)		
		3.5										
		S		ICE			ICE		ICE		ICE	
		0.5	20.6	21.5	---	4.8	4.8	---	0	292	311	---
	Oppelt	1.0	20.7			5.3	5.2(.8)		0	388	389(.8)	
		1.5				6.0(1.6)			0(1.6)	488(1.6)		
		2.0										
		2.5										
3/22/81		S	12.5	12.6	12.6	4.6	3.8	3.8	.3	942	956	940
		0.5	12.6	12.7	12.7	4.2	3.8	4.0	.3	956	956	956
		1.0	12.5	12.8		4.1	3.8		.2	956	956	
	Kurtz	1.5	12.8			3.9	3.9(1.5)		.2	956	956(1.5)	
		2.0	12.7			3.8			.2	956		
		2.5	12.6			3.9			.2	956		
		3.0				5.0(3.0)			.3(3.0)	1083(3.0)		
		3.5										
		S	11.7	11.9	d	5.1	4.8	d	0	320	328	d
		0.5	11.7	12.0		4.7	4.3		0	322	335	
	Oppelt	1.0	11.9			4.5	4.5(.7)		0	322	325(.7)	
		1.5				4.3(1.5)			0(1.5)	330(1.5)		
		2.0										
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (°/oo)	Sp. Cond. (µmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
4/5/81		S[a]	11.3	11.3	11.3	5.6	5.5	5.5	.2	878	893	909
		0.5	11.4	11.4	11.4	5.2	5.2	5.6	.2	911	926	924
		1.0	11.3	11.3		5.2	5.2		.2	926	926	
	Kurtz	1.5	11.4	11.2		5.2	5.2(1.6)[b]		.2	926	942(1.6)	
		2.0	11.4			5.2			.2	942		
		2.5	11.2			5.2			.2	942		
		3.0	11.2			5.2			.2	942		
		3.5				5.7(3.2)			.2(3.2)	924(3.2)		
		S	11.2	11.3	d	6.7	6.3	d	0	351	363	d
		0.5	11.2	11.1		6.2	6.2		0	360	363	
	Oppelt	1.0	11.3			6.0	6.2(.8)		0	360	368(.8)	
		1.5				6.0(1.5)			0(1.5)	365(1.5)		
		2.0										
		2.5										
4/26/81		S	11.6	11.7	11.7	14.8	14.3	14.3	.2	873	888	888
		0.5	11.8	11.9	11.9	14.5	14.1	14.1	.2	873	888	888
		1.0	12.1	12.4		12.8	12.7		.2	896	896	
	Kurtz	1.5	13.5	13.2		11.5	11.4(1.5)		.2	911	938(1.5)	
		2.0	12.7			11.1			.2	911		
		2.5	12.1			10.8			.2	911		
		3.0	11.5			10.3			.2	925		
		3.5				10.3(3.2)			.2(3.2)	925(3.2)		
		S	10.1	10.1	d	15.6	15.3	d	0	370	380	d
		0.5	10.2	10.5		14.0	14.1		0	374	373	
	Oppelt	1.0	10.7			12.4	13.0(.7)		0	379	374(.7)	
		1.5				11.9(1.4)			0(1.4)	406(1.4)		
		2.0										
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (°/oo)	Sp. Cond. (µmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
5/10/81		S[a]	9.6	9.7	9.6	10.9	10.9	10.9	.2	898	898	898
		0.5	9.6	9.8	9.7	10.9	10.9	11.0	.2	898	898	898
		1.0	9.6	9.7		11.0	11.0		.2	898	898	
	Kurtz	1.5	9.7			11.0	11.0(1.5)[b]		.2	898	898(1.5)	
		2.0	9.6			11.0			.2	898		
		2.5	9.5			11.0			.2	898		
		3.0				11.0(3.0)			.2(3.0)	911(3.0)		
		3.5										
		S	10.6	10.6	d	11.6	11.6	d	0	388	391	d
		0.5	10.5	10.6		11.5	11.6		0	392	391	
	Oppelt	1.0	10.6			11.5	11.8(.7)		0	396	399(.7)	
		1.5				11.7(1.4)			0(1.4)	401(1.4)		
		2.0										
		2.5										
5/25/81		S	8.3	8.2	8.2	14.7	14.7	14.8	.2	898	898	898
		0.5	8.3	8.2	8.2	14.8	14.8	14.9	.2	898	898	923
		1.0	8.1	8.1		14.9	14.9		.2	898	898	
	Kurtz	1.5	8.2			14.9	14.9(1.4)		.2	898	923(1.4)	
		2.0	8.2			14.9			.2	898		
		2.5	8.0			15.0			.2	910		
		3.0				15.0(2.9)			.2(2.9)	935(2.9)		
		3.5										
		S	8.7	8.8	d	12.7	12.7	d	0	421	425	d
		0.5	8.5	8.6		12.8	12.9		0	426	426	
	Oppelt	1.0	8.5			12.9	12.9(.6)		0	429	426(.6)	
		1.5				12.9(1.2)			0(1.2)	431(1.2)		
		2.0										
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (°C)			Salinity (°/oo)	Sp. Cond. (µmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
6/8/81		S[a]	7.9	8.0	8.0	20.4	20.3	20.4	.2	957	957	957
		0.5	8.0	8.1	8.1	20.4	20.3	20.4	.2	957	957	957
		1.0	8.0	8.1		20.4	20.3		.2	957	957	
	Kurtz	1.5	7.9			19.3	20.0(1.4)[b]		.2	952	957(1.4)	
		2.0	5.8			17.9			.2	955		
		2.5	4.1			16.2			.2	960		
		3.0				15.5(2.9)			.2(2.9)	960(2.9)		
		3.5										
		S	5.5	5.6	[d]	20.0	20.0	[d]	0	413	411	[d]
		0.5	4.1	4.1		19.3	19.4		0	414	416	
	Oppelt	1.0	2.9			18.9	19.0(.6)		0	427	440(.6)	
		1.5				17.4(1.2)			0(1.2)	461(1.2)		
		2.0										
		2.5										
6/22/81		S	8.6	8.7	8.7	18.0	18.0	18.0	.2	920	920	920
		0.5	8.7	8.7	8.7	18.0	18.0	18.0	.2	920	920	920
		1.0	8.5	8.5		18.0	18.0		.2	920	920	
	Kurtz	1.5	8.8			18.0	18.0(1.4)		.2	932	920(1.4)	
		2.0	8.5			18.0			.2	932		
		2.5	8.3			17.2			.2	956		
		3.0				17.1(2.9)			.2(2.9)	956(2.9)		
		3.5										
		S	9.9	9.9	[d]	17.8	17.8	[d]	0	348	354	[d]
		0.5	9.9	9.9		17.4	17.8		0	358	354	
	Oppelt	1.0	9.8			17.2	17.4(.6)		0	368	368(.6)	
		1.5				17.2(1.1)			0(1.1)	389(1.1)		
		2.0										
		2.5										

Appendix 6. Continued.

Date	Dugout	Depth	Dissolved O_2 (mg/l)			Temperature (^oC)			Salinity (o/oo)	Sp. Cond. (μmhos/cm)		
		Station:	1	2	3	1	2	3	1	1	2	3
7/6/81		S[a]	9.2	9.5	9.6	24.8	24.5	24.6	.2	930	930	930
		0.5	9.3	9.6	9.6	24.6	24.3	24.6	.2	940	949	940
		1.0	9.3	9.6		24.5	24.2		.2	930	949	
	Kurtz	1.5	7.8			22.1	23.1(1.3)[b]		.2	984	957(1.3)	
		2.0	5.0			20.0			.2	979		
		2.5	2.7			18.2			.2	1001		
		3.0				18.0(2.7)			.2(2.7)	966(2.7)		
		3.5										
		S	11.4	11.5	d	26.4	26.0	d	0	348	348	d
		0.5	6.6	6.2		24.0	23.6(.5)		0	356	362(.5)	
	Oppelt	1.0				23.1(.92)			0(.92)	410(.92)		
		1.5										
		2.0										
		2.5										

[a] Surface.

[b] Depth in parentheses.

[c] Broken oxygen bottles.

[d] Station 3 interferes with Station 2.